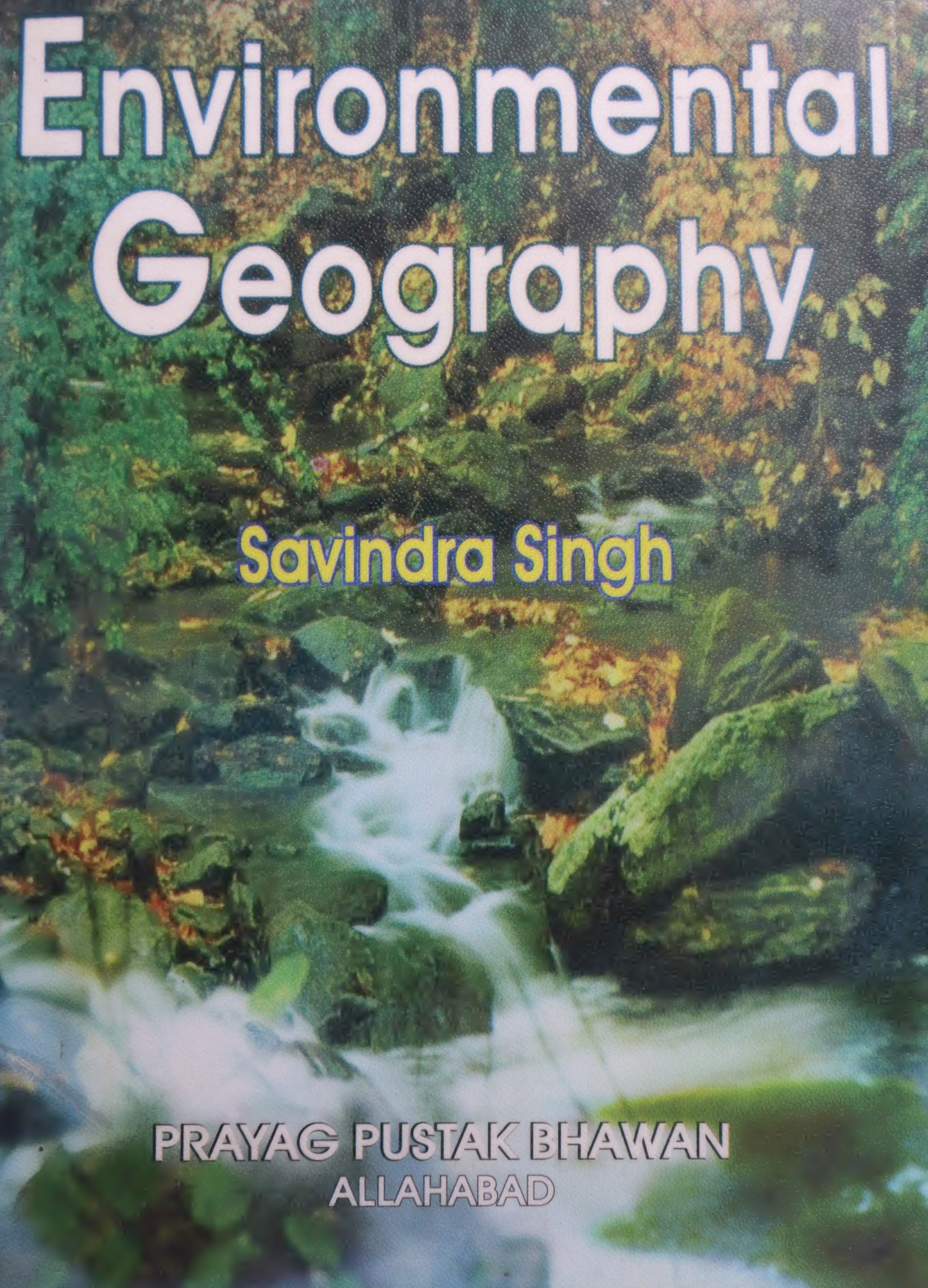

Environmental Geography

Savindra Singh

PRAYAG PUSTAK BHAWAN
ALLAHABAD

Environmental
Geography

ENVIRONMENTAL GEOGRAPHY

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PREFACE TO NEW EDITION

Since the introduction of the concept of environmental geography in 1989 (Savindra Singh, 1989) and the publication of the first edition of 'environmental geography' in 1991 (Savindra Singh, 1991) for the first time in India and abroad, the scope of this discipline has widened enormously. New thrust areas of global interest have emerged and have gained currency namely, global warming and climate change; natural hazards and disasters in terms of increase in their frequencies and severity and adverse impacts on biota in general and human beings in particular such as tropical storms, tsunami etc.; growing need for the reduction and management of natural hazards and disasters; biodiversity loss and its conservation; disaster management in India etc.

Keeping these facts in mind the author feel it necessary to revise and rewrite this book (environmental geography) so as to include the above mentioned new themes. It may be mentioned that initially this book contained only 19 chapters when its first edition was published in 1991. Later on two more chapters on 'environmental degradation and pollution in India', and 'global environmental problems and international cooperations' were added. Now the latest edition of 'environmental geography' includes 26 chapters wherein new chapters on 'climate change', 'natural disaster management', 'environmental resources', 'biodiversity, biosphere reserves and wildlife conservation', and 'disaster management in India' have been incorporated. Bisides, the chapters on 'man, atmospheric environment and global warming, 'environmental planning and management' etc. have been thoroughly revised and updated. The earlier chapter on 'extreme events, hazards and disasters' has been split into 3 independent chapters viz. 'natural hazards and disaster management' (theoretical aspects), 'terrestrial hazards and disasters', and 'atmospheric hazards and disasters'. Tsunami disaster has been given more focussed attention in chapters 17 and 18.

Latest materials have been added in the Edition of 2011. The bibliography has also been updated. The author is confident that this new edition of 'environmental geography' will be appreciated by the academic communities world over. The author express deep sense of gratitude for the proprietors of Prayag Pustak Bhawan for bringing out this new edition of 'environmental geography' in time.

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SAVINDRA SINGH

PREFACE

(First Edition)

Environment, once the focus of geographical study but subsequently neglected and pushed to the background has recently regained its position in earth sciences throughout the world. In fact, the environment has always been lurking in the background throughout the methodological debate in geography and its study in one way or the other has always been a recurring theme of the subject except between 1950 and 1970 when the discipline was overshadowed by the dominance of locational analysis and spatial organization studies using abstract mathematical models and statistical techniques. Consequently, the banner of the environment was carried away by the biologists but since 1970 the environmental studies have again gained currency in geography and most of the departments of geography of Indian and overseas universities have included its study in their undergraduate and postgraduate teaching and research programmes.

Environmental issues are today no longer confined to geography and allied disciplines but have also drawn the attention of common people as environmental degradation and pollution have assumed global dimension and are even threatening the very existence and survival of mankind. Ever-increasing greenhouse effects, creation of ozone hole and gradual depletion of ozone layer, Gulf war etc. have cautioned the scientists, administrators, academicians, social workers and common people alike against environmental hazards and disasters and possible holocaust. It is, therefore, desirable to examine various facts of the environment so that the interactions between technologically advanced 'economic man' and the environment and the processes leading to environmental degradation and pollution are properly understood, ecological resources are properly evaluated, environmental impact assessment is successfully carried out, pollution abatement programmes are scientifically formulated and implemented and environmental planning and management programmes are properly executed to maintain ecological balance and ecosystem stability at local, regional and global levels.

Keeping these facts in mind the authour has ventured to present a comprehensive account of the environment with geographical view points. The preference for the caption 'Environmental Geography' has been deliberately made so that the subject should look more geographical in character and may be easily differentiated from other disciplines studying the environent. Similarly, the nomenclature of the themes of environmental studies as 'environmental geography' in place of 'geography of environment' has been chosen to lay more emphasis on the application of geographical information (both physical and human) for the solution of environmental crises and problems which have currently plagued the whole humanity. In fact, the environmental geography may serve as a bridge between physical and human branches of geography and it may provide common platform for geographers in general and environmental geographers in particular to interact with other allied life and earth scientists.

The entire theme of the book has been organised in 21 chapters. The conceptual aspects of environmental geography and the environment have been discussed in the 1st five chapters wherein the concepts of environmental geography (Chapte 4) and ecosystem (Chapter 5) have been elaborated. Characteristic features of various components of the biospheric ecosystem have been described in Chapter 6. Various aspects of soil system have been detailed out in the 7th Chapter on the ground that soils support the base of the trophic levels of the food chains and food webs. The ecosystem dynamics and energetics have been elaborated in Chapters 8 and 9 in order to explain the movement and circulation of energy and matter through different components and storage pools of the biospheric ecosystem. Since plants and animals are significant biotic components of the biospheric ecosystem, spatial and temporal aspects of ecological changes together with other aspects of plants and animals have been discussed in the 10th and 11th Chapters. Regional ecological chracteristics at biome level have been described in the 12th Chapter. Man's interactions with the environment and consequent responses and their remedial measures have been analysed in Chapters 13 (man-induced soil erosion and sedimentation), 16 (environmental degradation), 17 (extreme events, hazards and disasters) and 18 (environmental pollution), methods and approaches to the environmental planning and management together with the examples of a few typical programmes and projects have been discussded in the 19th Chapter, environmental degradation and pollution in India and climatic changes have been elaborated in the 20th and 21st Chapters respectively.

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Physical Geography (SIZE : 20" × 30", PAGES : 648) : Chapters : **Geomorphology :** 1. nature of physical geography, 2. origin of the earth, 3. age of the earth, 4. structure of the earth's interior, 5. continents and ocean basins, 6. theory of isostasy, 7. earth's movements, 8. rocks, 9. vulcanicity and volcanoes, 10. earthquakes, 11. mountain building, 12. plateau, 13. plains, 14. lakes, 15. weathering and mass movements, 16. cycle of erosion, rejuvenation and polycyclic relief, 17. drainage systems and patterns, 18. running water (river) and fluvial landforms, 19. groundwater and karst topography, 20. sea waves and coastal landforms, 21. wind and aeolian landforms, 22. glaciers and glaciated topography, 23. periglacial processes and landforms; **Oceanography :** 24. reliefs of the ocean basins, 25. temperature of the ocean water, 26. salinity, 27. ocean deposits, 28. ocean tides, 29. ocean currents, 30. coral reefs and atolls, 31. marine resources; **Climatology :** 32. composition and structure of atmosphere, 33. insolation and heat budget, 34. temperature, 35. air pressure and atmospheric circulation, 36. humidity and precipitation, 37. air masses, 38. frontogenesis, cyclones and anticyclones, 39. classification of climates and climatic types, 40. **Biosphere**, 41. ecosystem and ecology, 42. biosphere : an ecosystem, 43. plant community, 44. animal community, and 45. biomes.

Geomorphology (SIZE : 20" × 30", PAGES : 652) : Chapters : 1. Nature of geomorphology, 2. fundamental concepts in geomorphology, 3. theories of landform development, 4. climatic geomorphology, 5. constitution of the earth's interior, 6. continents and ocean basins, 7. theory of isostasy, 8. rocks, 9. earth's movement, 10. structural geomorphology, 11. plate tectonics, 12. vulcanicity and landforms, 13. mountain building, 14. weathering and massmovement, 15. hillslope, 16. cycle of erosion, rejuvenation and polycyclic reliefs, 17. denudation chronology, erosion surfaces and peneplains, 18. drainage systems and patterns, 19. morphometry of drainage basins, 20. river valleys, graded river and profile of equilibrium, 21. channel morphology, 22. fluvial geomorphology, 23. karst geomorphology, 24. coastal geomorphology, 25. arid and semi-arid geomorphology, 26. glacial geomorphology 27. periglacial geomorphology, 28. regional geomorphology, 29. applied geomorphology, 30. anthropogenic geomorphology, and 31. climatic change and quarternary geomorphology.

Climatology (SIZE : 20" × 30", PAGES : 504) Chapters : 1. Climatology : Basic concepts, 2. origin, composition and structure of atmosphere, 3. insolation and energy (heat) balance, 4. temperature, 5 atmospheric pressure and motion, 6. general atmospheric circulation, 7. local and seasonal winds, 8. atmospheric humidity and condensation, 9. fogs, clouds and precipitation, 10. air masses, 11. frontogenesis, cyclones and anti-cyclones, 12. atmospheric extreme events and hazards, 13. classification of climates, 14. climatic types and biomes, 15. climatic change, 16. global warming and change in atmospheric chemistry, 17. weather forecasting, 18. applied climatology.

Oceanography (SIZE : 20" × 30", PAGES : 460) : Chapters : 1. nature of oceanography, 2. origin of ocean basins, 3. ocean morphology and bottom relief, 4. physical properties of ocean water, 5. salinity of seawater, 6. marine sediments and deposits, 7. atmosphere-sea interactions, 8. sea waves, shoreline processes and coastal scenery, 9. tsunamis, 10. surface ocean currents, 11. water masses and deep currents, 12. tides, 13. coral reefs, 14. ocean habitats, 15. marine biomes (Biozones) and sea organisms, 16. marine ecology and biological productivity, 17. marine resources, 18. man and oceans.

Environmental Geography (SIZE : 20" × 30", PAGES : 648) : Chapters : 1. environmental geography - concepts, 2. environment, 3. man-environment relationships, 4. ecology, 5. ecosystem, 6. biosphere as an ecosystem, 7. soil system, 8. ecological production and energy flow in the ecosystem, 9. circulation of elements in the ecosystem and biogeochemical cycles, 10. plant kingdom, 11. animal kingdom, 12. biomes, 13. man, atmospheric environment and global warming, 14. man and environmental processes, 15. man-induced soil erosion and sedimentation, 16. environmental degradation, 17. extreme events, hazards and disasters, 18. environmental pollution, 19. environmental planning and management, 20. environmental degradation and pollution in India,and 21. climatic changes.

Biogeography (SIZE : 20" × 30", PAGES : 360) : Chapters : 1. nature of biogeography, 2. ecosystem and ecology, 3. biosphere as an ecosystem, 4. soil system, 5. biogeographical processes, 6. plant community and biotic succession, 7. evolution, dispersal and distribution of plants, 8. major plant formations and biome, 9. animal community, 10. biogeographical regions, 11. marine biogeography, 12. marine ecology and biological productivity, 13. biodiversity, biosphere reserve and wildlife conservation, 14. forest conservation in India, 15. island biogeography.

भौतिक भूगोल का स्वरूप (आकार : 20" × 30", पृष्ठ : 711) : अध्याय – 1. भौतिक भूगोल : परिभाषा, विषय क्षेत्र तथा विकास, 2. पृथ्वी की उत्पत्ति, आयु तथा भूगर्भिक इतिहास, 3. पृथ्वी की आन्तरिक संरचना, 4. महाद्वीप एवं महासागरीय बेसिन की उत्पत्ति, 5. भूसन्तुलन का सिद्धान्त, 6. भूसंचलन तथा तज्जनित स्थलाकृतियां, 7. पृथ्वी की रचना सामग्री—चट्टान, 8. मृदा : संघटन, उत्पत्ति तथा वर्गीकरण, 9. ज्वालामुखी एवं ज्वालामुखी स्थलाकृतियां, 10. भूकम्प एवं भूकम्प विज्ञान, 11. पर्वत एवं पर्वत निर्माण के सिद्धान्त, 12. पठार, 13. मैदान, 14. झील, 15. अपक्षय : स्थैतिक प्रक्रिया, 16. अपरदन चक्र, नवोन्मेष तथा बहुचक्रीय स्थलाकृति, 17. अपवाह तंत्र तथा प्रतिरूप, 18. नदी के कार्य तथा उत्पन्न स्थलाकृति, 19. भूमिगत जल के कार्य तथा उत्पन्न स्थलाकृति (कार्स्ट स्थलाकृति), 20. सागरीय जल के कार्य तथा उत्पन्न स्थलाकृति, 21. पवन के कार्य तथा उत्पन्न स्थलाकृति, 22. हिमनद के कार्य तथा उत्पन्न स्थलाकृति, 23. परिहिमानी प्रक्रम एवं स्थलरूप, 24. महासागरीय नितल के उच्चावच्च, 25. महासागरीय जल का तापमान एवं घनत्व, 26. महासागरीय लवणता, 27. महासागरीय निक्षेप, 28. महासागरीय ज्वार,

29. महासागरीय तरंगें तथा धारायें, 30. प्रवाल एवं प्रवाल विरंजन, 31. सागरीय संसाधन, 32. वायुमण्डल का संघटन एवं संरचना, 33. सूर्यातप तथा ऊष्मा सन्तुलन, 34. वायु का तापमान, 35. वायुमण्डलीय दबाव एवं गतियाँ, 36. वायुमण्डल का सामान्य परिसंचरण, 37. स्थानीय एवं मौसमी हवायें, 38. वायुमण्डलीय स्थिरता, अस्थिरता एवं सन्तुलन, 39. वायुमण्डलीय आर्द्रता तथा वर्षा, 40. वायुराशियां, 41. वाताग्र जनन, चक्रवात एवं प्रतिचक्रवात, 42. जलवायु का वर्गीकरण, 43. जलवायु प्रकार तथा जलवायु प्रदेश, 44. जीवमण्डल तथा उसके संघटक, 45. पारिस्थितिक तंत्र एवं पारिस्थितिकी, 46. जीवमण्डल : एक पारिस्थितिक तंत्र, 47. पादप समुदाय, 48. जन्तु जगत, 49. बायोम, 50. जैवविविधता।

भूआकृति विज्ञान का स्वरूप (आकार : 20" × 30", पृष्ठ : 652) : अध्याय 1 : भूआकृति विज्ञान का स्वरूप, 2 : भ्वाकृतिक संकल्पनायें, 3 : स्थलरूपों के विकास के सिद्धान्त, 4 : जलवायु भूआकारिकी तथा आकारजनक प्रदेश, 5 : पृथ्वी की आन्तरिक संरचना, 6 : महाद्वीप एवं महासागरीय बेसिन की उत्पत्ति, 7 : भूसंतुलन का सिद्धान्त, 8 : भूसंचलन तथा तज्जनित आकृतियां, 9 : संरचनात्मक भूआकारिकी, 10 : प्लेट विवर्तनिकी, 11 : ज्वालामुखी स्थलाकृतियां, 12 : पर्वत निर्माण के सिद्धान्त, 13 : अपक्षय तथा द्रव्यमान संचलन, 14 : ढाल विश्लेषण, 15 : अपरदन चक्र, नवोन्मेष तथा बहुचक्रीय स्थलाकृति, 16 : समप्राय मैदान तथा पैनप्लेन, 17 : अनाच्छादन कालानुक्रम तथा अपरदन सतह, 18 : अपवाह तंत्र तथा प्रतिरूप, 19 : आकारमिति, 20 : नदी घाटी का विकास, 21 : जलधारा आकारिकी, 22 : जलीय भूआकारिकी, 23 : कार्स्ट भूआकारिकी, 24 : तटीय भूआकारिकी, 25 : शुष्क एवं अर्द्धशुष्क भूआकारिकी, 26 : हिमानी भूआकारिकी, 27 : परिहिमानी भूआकारिकी, 28 : प्रादेशिक भूआकारिकी, 29 : व्यावहारिक भूआकारिकी, 30 : मानवजनिक भूआकारिकी, 31 : जलवायु परिवर्तन तथा क्वाटरनरी भूआकारिकी।

जलवायु विज्ञान (आकार : 20" × 30", पृष्ठ : 528) : अध्याय - 1. जलवायु विज्ञान : परिभाषा, विषय क्षेत्र तथा विकास, 2, वायुमण्डल की उत्पत्ति, संघटन एवं संरचना, 3. सूर्यताप तथा ऊर्जा (ऊष्मा) सन्तुलन, 4. तापमान, 5. वायुमण्डलीय दबाव एवं गतियां, 6. वायुमण्डल का सामान्य परिसंचरण, 7. स्थानीय एवं मौसमी हवायें, 8. वायुमण्डलीय आर्द्रता एवं संघनन, 9. कुहरा, बादल तथा वर्षा, 10. वायु राशियां, 11. वाताग्रजनन, चक्रवात एवं प्रतिचक्रवात, 12. वायुमण्डलीय चरम घटना तथा प्रकोप, 13. जलवायु का वर्गीकरण, 14. जलवायु प्रकार एवं बायोम, 15. जलवायु परिवर्तन, 16. भूमण्डलीय ऊष्मन तथा वायुमण्डलीय रासायनिक संरचना में परिवर्तन, 17. मौसम पूर्वानुमान, 18. व्यावहारिक जलवायु विज्ञान।

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जलवायु एवं समुद्र विज्ञान (आकार : 20" × 30", पृष्ठ : 352) : अध्याय - 1. जलवायु विज्ञान : प्रकृति तथा विषय क्षेत्र, 2. वायुमण्डल का संघटन एवं संरचना, 3. सूर्यातप तथा ऊर्जा (ऊष्मा) सन्तुलन, 4. वायु का तापमान, 5. हरितगृह प्रभाव तथा भूमण्डलीय ऊष्मन, 6. वायुमण्डलीय दबाव एवं गतियां, 7. वायुमण्डल का सामान्य परिसंचरण, 8. स्थानीय एवं मौसमी हवायें, 9. वायुमण्डलीय स्थिरता, अस्थिरता एवं सन्तुलन, 10. वायुमण्डलीय आर्द्रता तथा वर्षा, 11. वायुराशियां, 12. वाताग्र जनन, चक्रवात एवं प्रतिचक्रवात, 13. जलवायु का वर्गीकरण, 14. जलवायु प्रकार तथा जलवायु प्रदेश, 15. भूमण्डलीय ऊष्मन, 16. जलवायु परिवर्तन, 17 : व्यावहारिक जलवायु विज्ञान, 18. समुद्र विज्ञान की प्रकृति, 19. सागरीय नितल के उच्चावच्च, 20. महासागरीय जल का तापमान एवं घनत्व, 21. महासागरीय लवणता, 22. महासागरीय निक्षेप, 23. महासागरीय ज्वार, 24. महासागरीय तरंगें तथा धारायें, 25. प्रवाल एवं प्रवाल विरंजन, 26. सागरीय संसाधन, 27. सागरीय जैव कटिबन्ध तथा सागरीय जीव, 28. प्लेट विवर्तनिकी एवं महासागर।

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1

ENVIRONMENTAL GEOGRAPHY

(Definitions, Scope and Concepts)

The study of environment in one way or the other has always been recurring theme in geography but between 1950 and 1970 the discipline was overshadowed by the dominance of locational analysis and spatial organisation studies and the use of abstract mathematical and statistical techniques in geographical enquiries. Consequently, the banner of environment was carried away by the biologists. Since 1970 the environmental studies have gained currency in geography and most of the departments of geography of Indian Universities have included the study of environment under different nomenclature (e.g. ecology and environmental management, environmental studies, environmental science, geography of environmental management, environmental management etc.) in their undergraduate and postgraduate teaching programmes. The author has opted for the caption '*environmental geography*' for the study of various aspects of the environment on the ground that the subject must look more geographical in character and it can be differentiated from other disciplines studying environment because geography studies the spatial attributes of mater and phenomena on the earth's surface at different spatial and temporal scales. Moreover, the nomenclature of the theme of environmental studies as '*environmental geography*' instead of '*geography of environment*' lays more emphasis on the application of geographical information (both physical and human) to the solution of environmental problems. To my mind, the environmental geography may serve as a bridge between physical and human branches of geography on the one hand and it may associate geographers in general and environmental geographers in particular with other allied life and earth scientists on the other hand.

1.1 ENVIRONMENTAL GEOGRAPHY : MEANING AND DEFINITIONS

Probably K. Hewitt and F.K. Hare first used the term of 'environmental geography' in Man and Environment; Conceptual Frameworks (Commission on College Geography Resource Paper 20) in the year 1973 who remarked that 'the main needs of environmental geography today are a deeper fusion of ideas and results from the life sciences. It was realized that ecological inputs in geographical studies of environment would make the discipline of geography more focussed subject. This is clearly evident from the assertion of S.R. Eyre (1964) that 'a more ecological approach' enhances the prestige of geographers within the academic world'. According to Eyre 'by adopting an ecological view point geographers can stand to rid themselves of 'naive determinism' and misinterpretation in both human and physical geography' (C.C. Park 1980).

It was the year 1989 when Savindra Singh (Singh, 1989) attempted to define environmental geography and determine its scope in his research paper entitled '*environmental geography : conceptual frameworks*' (National Geographer, 1989) and published the first comprehensive text and reference book entitled '*environmental geography*' in 1991. This led to widespread proliferation of environmental geography as a distinct branch of geography and now most of the Indian universities have included environmental geography in their undergraduate and postgraduate geography syllabi.

Emphasising the fact that the basic approach to the study of man-environment relationships, the core of environmental geography, is ecological analysis of spatial attributes of interrelationships between technological advanced man and natural environment of the planet earth in terms of ecosystem. Savindra Singh defined environmental geography in 1989 as follows :

"Thus broadly speaking, environmental geography may be defined as the study of spatial attributes of interrelationships between living organisms and natural environment in general, and between technologically advanced 'economic man' and his natural environment in particular in temporal and spatial framework."

Let us build up the definition of environmental geography step by step so that the final definition may include all aspects of environmental geography so that it may be more flexible and broad based and may very precisely reveal the scope of the subject as follows :

(1) *'Environmental geography is basically the study of environment.'* If this is so, why it should not be termed as 'geography of environment'? The answer is easy, the term environmental geography lays more emphasis on man-environment relationships vis-a-vis man-environment interactions, causes thereof and responses therefrom. On the other hand, 'geography of environment' focuses more on the study of characteristics and spatial and temporal distribution of different components of environment e.g. land, air, water, society etc. It does not mean that environmental geography does not focus on the spatial and temporal aspects of environment. Thus, the definition of environmental geography has to be broadened as follows :

(2) *Environmental geography is the study of systematic description of different components of environment and interactions of man with these components.*

The study of characteristic features of the components of the environment such as abiotic components, biotic components and energy components and interactions between these components and among biotic components requires spatial and temporal units. The *'geobiosystems'* in terms of ecosystems of different spatial scales become the ideal spatial units for the study of environmental geography. Thus, the definition of environmental geography may be further broadened as follows :

(3) *'Environmental geography is the study of characteristic features of various components of the environment, the interactions between and among the components in a geoecosystem in terms of ecosystem of varying spatial and temporal scales.'*

The study of the functioning of the geoecosystem (ecosystem) through various physical, chemical and biological processes is equally important in environmental geography. Thus, the definition of environmental geography is further elaborated as follows :

(4) *'Environmental geography studies the characteristic features of various components of the geoecosystem (environmental system, ecosystem), the functioning of the ecosystem through the input of energy; the physical, chemical and biological processes which interlink the components; and the interactions between and among the components of the ecosystem.'*

It may be pointed out that the functioning of ecosystem and interactions between and among the components of ecosystem cause environmental problems of varying magnitudes. This aspect should also be included in the definition of environmental geography.

(5) *Thus, environmental geography may be defined as the study of the characteristic features of various components of the geoecosystem, the functioning of geoecosystem through the input of energy; the physical, chemical and biological processes which interlink the components; the interactions between and among the components of geoecosystem; and the environmental problems (pollution and environmental degradation) imanating from such interactions.'*

The management of different environmental problems resulting from the interactions between abiotic and biotic (mainly man) components also forms very important aspect of environmental geography. Thus, after including all the aforesaid aspects, the final definition of environmental geography may be formulated as follows :

(6) *Thus, "environmental geography may be defined as that branch of geography which studies the characteristics, composition and functions of different components of the natural environmental system (including man as a biological organism-a physical man), mutual interdependence of different components, various processes that link the components, the interactions of different components with each other and among themselves and consequent responses (environmental problems) in spatial and temporal context in terms of 'geoecosystem,' as well as interactions of technologically advanced 'economic man' with different components of natural 'geoecosystem' and resultant modifications and changes in the natural geoecosystem leading to environmental degradation and pollution, the techniques and strategies of pollution control measures and management of ecological resources" (Savindra Singh, 1989).*

1.2 SCOPE OF ENVIRONMENTAL GEOGRAPHY

The interface of air, water and land, forming life supporting layer, known as biosphere, is the broadest geoecosystem which is the spatial unit for the study of environmental geography. The prime concern of environmental geography is, thus, to study the components of natural environment separately and together, their linkages at various levels through environmental (physical) and biological processes and human responses to environment vis-a-vis man-environment relationships.

The subject matter of environmental geography has been broadly elaborated while developing the definition of environmental geography in the preceding section 1.1 of this chapter. The scope of the study of environmental geography may be grouped into 9 major subfileds e.g. (1) the **geoecosystem** or simply **ecosystem** as study unit, (2) the functioning of ecosystem including circulation of energy and matter and ecosystem productivity, (2) temporal changes in ecosystem : evolution of plants and animals; and ecological succession; (4) spatial ecological changes; distribution and dispersal of plants and animals; (5) global environmental problems; (6) environmental hazards and disasters; (7) man and environmental processes; (8) environmental degradation and pollution; and (9) environmental management (fig. 1.1).

(1) **Geoecosystem (ecosystem) :** Ecosystem is the basic ecological unit for the study of various aspects of environmental geography. This group includes the study of the following aspects of ecosystem :

- ➤ meaning and components of ecosystems,
- ➤ ecosystem characteristics,
- ➤ ecosystem types, and
- ➤ ecological principles,

(2) **Ecosystem functioning :** The ecosystem functions through the input of solar energy and biotic and abiotic matter. The following are included in the study of ecosystem function :

- ➤ sources and pattern of energy,
- ➤ circulation of energy in the ecosystem,
- ➤ ecological productivity and production,
- ➤ circulation of matter in the ecosystem,
- ➤ biogeochemical cycles, and
- ➤ ecosystem stability and instability.

(3) **Temporal ecological changes :** include the consideration of the following aspects of plant and animal communities :

- ➤ evolution of plants and animals,
- ➤ evolutionary history of world plant cover,
- ➤ successional development of plant communities and ecosystem,
- ➤ extinction of species, and
- ➤ climax vegetation.

(4) **Ecological changes in space :** refers primarily to spatial changes in the distribution of plants and animals in the world wherein the following aspects are of primary concern :

- ➤ dispersal of plants and animals,
- ➤ world distribution of plants and animals,
- ➤ ecological variatins at global level,
- ➤ ecological variations at regional and local scales;
- ➤ man-induced ecological changes, and
- ➤ environmental controls of ecological variations and changes.

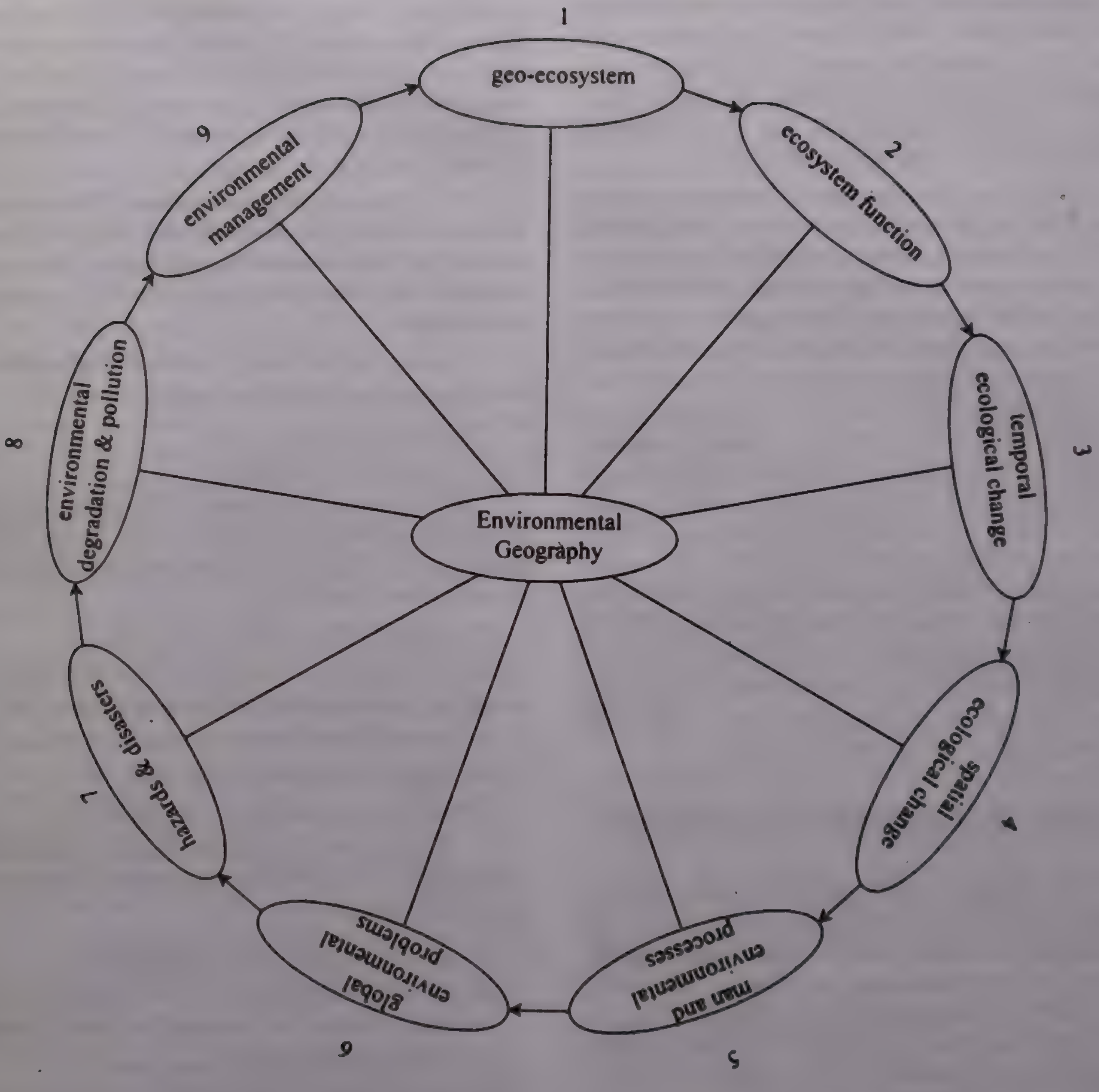

1
geo-ecosystem
2
ecosystem function
3
temporal ecological change
4
spatial ecological change
5
man and environmental processes
6
global environmental problems
7
hazards & disasters
8
environmental degradation & pollution
9
environmental management
Environmental Geography

Fig. 1.1 : Scope of Environmental Geography.

(5) **Global environmental problems** : include those problems which are caused mainly by anthropogenic processes. Such problems are related to the changes in the atmospheric chemistry as follows :

- global radiation balance,
- anthropogenic changes in global radiation/heat balance,
- indicators of global warming,
- process of global warming : ozone depletion and green house effect,
- global warming and climate changes,
- global warming and ecological changes,
- global changes in atmospheric chemistry, and
- international cooperations for taming global warming.

(6) **Environmental hazards and disasters** : include both natural and anthropogenic hazards and disasters. This aspect lays more emphasis on the study of the following :

- identification and listing of hazards and disasters,
- classification of hazards and disasters,
- causes and consequences of hazards and disasters, and
- disasters reduction and management.

(7) **Man and environmental processes** : are significant aspects of environmental geography because increased human economic activities have enormously modified different environmental processes which have upset the natural ecosystem. This aspect includes the consideration of the following :

- man and hydrological processes,
- man and weathering and mass movement,
- man and coastal processes,
- man and river process,
- man and periglacial processes,
- man and subsurface processes,
- man and pedological processes, and
- man induced soil erosion and sedimentation.

(8) **Environmental degradation and pollution :** includes the consideration of the following aspects within environmental geography :

- processes and causes of environmental degradation,
- agricultural development and environmental degradation,
- deforestation and environmental degradation,
- population growth and environmental degradation,
- urbanization and environmental degradation,
- industrialization and environmental degradation
- modern productive technology and environmental degradation,
- air pollution, water pollution, solid waste pollution, soil pollution, and noise pollution, and
- controls of environmental degradation and pollution.

(9) **Environmental management** : is the most significant aspect of environmental geography which includes the following :

- processes of environmental management,
- methods of evaluation of ecological resources,
- ecological basis of environmental management,
- ecological resources,
- preservation and conservation of ecological resources,
- biosphere reserve, and
- environmental impact assessment.

1.3 GEOGRAPHY AND ECOLOGY

Geography is a spatial science which studies spatial attributes of various phenomena on the earth's surface through time. In other words, phenomenon or sets of phenomena which exist in space-time framework become the subject matter of geography. Besides this traditional definition in a highly generalised sense, geography has been variously defined as the study of areal distribution of phenomena, spatial patterns, locational analysis, human ecology, man-land relationships, environment-man and man-environment relationships, spatial organisation, ecological studies etc. Peter Haggett (1972, Geography, A Modern Synthesis) has attempted to integrate the structure of geography and various approaches of study into three broad modes of analysis viz. (i) Spatial analysis involves the study of locational variation of significant property or series of properties of objects on the earth's surface, (ii) Ecological analysis interrelates human and environmental variables and interprets their links, and (iii) Regional complex analysis combines the results of spatial and ecological analyses. Thus, it appears that there has always been ecological tinge in geographical enquiry. Even a renowned American geomorphologist, W.M. Davis observed that 'geography is primarily devoted to analysing the relationships between inorganic control and organic response, and in many ways the geographer has traditionally been closely concerned with the subject matter of ecology' (C.C. Park, 1980).

The importance of ecological studies within the field of geography has been recently substantiated due to (i) increasing interests, shown by ecologists in environmental problems, (ii) growth of environmental science as a link between geography and ecology, (iii) increased interest of the geographers in studying the problems and solution of evaluation of resources and their proper management, and (iv) the orientation of applied geography to study complex interrelationships between man and physical environment and between nature and society.

Ecological perspective in geography has been stressed and highlighted by a few scientists. S.R. Eyer (1964) is of the opinion that 'a more ecological approach enhances the prestige of geographers within the academic world'. I.G. Simmons (1966) has advocated the application of ecological approach to geographical enquiry because it helps in the assessment of cultural factors in land use and land use changes and in identifying the process and mechanism of manipulations of ecological system by man; while D.R. Stodart has stressed the significance of the adoption of ecològical view point to geographers on the ground that geographers with ecological orientation towards geographical enquiry may be able to tide over the deterministic approach and strong biases within physical and human geography as ecological approach plays a vital role in bridging physical and human geography.

It may be pointed out that ecological studies traditionally fall within biogeography which normally studies the distribution of plants and animals (excluding man) and patterns of life (of plants and animals-biological materials) on the surface of the earth and the factors which are responsible for spatial variations in their distribution. Biogeography has slightly different meaning for different disciplines. For example, biogeographers concentrate on distributional aspect of biological materials as well as on the relationships between organisms and physical environment at local, regional and global levels and the most common lines of study are populations, communities and larger biotic units such as biome representing life zones of the earth's surface while biologists lay more emphasis on the study of individual organism and its physiological, morphological and behavioral functions. Zoologists use biogeography to mean the evolution of animal patterns through geological periods. The ecologists study both individuals and species (autecology) and communities and interactions between populations and physical environment (synecology) and thus 'ecologists are perhaps the nearest scientific relatives of biogeographers'.

The boundaries between biogeoraphy and ecology are so overlapping that it becomes difficult, if not impossible, to differentiate these two disciplines. However, these two disciplines may be differentiated on the basis of scale of study and major emphasis on a few themes. For example, ecological studies in environmental geography/ biogeography involve large spatial units such as regional, continental, oceanic or global (whole biosphere) ecosystems. The study of these larger spatial units having both biotic and abiotic components falls within the realm of geography (more specifically environmental geography and biogeogrpahy) whereas local ecosystems of small spatial dimension having both biotic and abiotic components form the study unit of ecology. Even if the scale of study units is ignored, a line of difference may be drawn between ecology and environmental geography and biogeography in terms of spatial organisation. If the focus is on spatial organisation of ecosystems or within an ecosystem, the study of ecosystem becomes exclusively geographical.

Further, ecological study mainly concerns with the relationships between individual species of organisms whereas geographical approach lays more emphasis on functional linkages between the living and non-living (biotic and abiotic) components of ecosystems. Though ecologists also study such relationships but geographers excel in this field because of their superior knowledge of abiotic components (because of richer heritage of detailed knowledge of geomorphology, climatology and oceanography). Geographers, at least physical geographers, understand the machanism of environmental processes (physical processes) far better than any life scientists and ecologists and since man and his social, cultural, political and economic activities resulting into cultural landscapes are studied in human geography, geographers again become well equipped to undertake ecological studies in different ecosystems of different sizes because the geographers are able to observe and evaluate the alteration and modification of environmental processes (physical processes) by human activities in a far better way than the ecologists. Thus the geographers are better placed to study the characteristics of environment and man-environment relationships. It may be concluded that geography with ecological perspective can study man-environment relationship, identify environmental problems, and suggest and formulate economically and socially sound environmental planning and management for the conservation of natural and ecological resources. Therefore, 'the main needs of environmental geography today are a deeper fusion of ideas and results from life sciences' (K. Hewitt and F.K. Hare, 1973) and from ecology.

1.4. ENVIRONMENTAL GEOGRAPHY AND RELATED SCIENCES

As elaborated in the preceding sections, environmental geography is basically the study of spatial attributes of interrelationships between biotic and abiotic (physical) components and between technologically advanced man and the components of the natural environmental system (geoecosystem). The basic fundamental unit for the study of such interrelationships is the biosphere (geoecosystem) or part thereof. The abiotic components (physical components-land, air, water and energy) are closely related to geography particularly physical geography (geomorphology, climatology, soil geography etc.), geology (quaternary studies, physical geology, petrology etc.), geophysics and atmospheric sciences (meteorology) all of which belong to the major field of earth sciences. Physics and chemistry (mainly bio-chemistry) are also related to the abiotic/physical components though via geology and geophysics. These subfields of earth sciences are related to each other and provide vital information about the composition and characteristics of various aspects of physical or abiotic components of the biospheric geoecosystem. Since physical geography studies all of the elements of abiotic component based on its own resources and on the information derived from geology, geophysics and atmospheric sciences, it is more closely related to environmental studies and therefore to environmental geography.

Further, geography is the only discipline that can pursue the study of environment in totality because :

(i) It studies the spatial attributes of all the phenomena including man in a given space and highlights complex man-environment relationships at different stages and phases in a time-space continuum while other sciences study individual phenomenon and do not bother for spatial organisation.

(ii) Being an integrating science geography synthesises all the elements and components of planet earth into one boby and links social sciences with natural sciences.

(iii) It lays stress on the 'synthesis of all near surface spheres into one interacting system' (Annuchin, 1974). That is to say that geography studies the biosphere (the interface of air, land and water) in totality (all components of biosphere-abiotic and biotic-their characteristics and inter-relationships).

(iv) As regards the physical system, it is geography that excels other sciences because geographers have the knowledge of structure (of geomaterials), geomorphic processes, climate, vegetation and soils while other scientists specialize in only one of these aspects.

(v) 'Geographers besides indentifying complex relationships between man and physical environment have the capability of locating the distribution of such relationships in space, mapping them and exploring the causes of variations.

(vi) 'Geographers recognise that the quality of life layer varies from place to place in terms of richness or poverty of life-form capable of being supported' (A.N. Strahler and A.H. Strahler, 1976, p.2). Geographers are the only scientists who can recognise and identify the environmental regions, locate them in space and present them on maps.

The biotic component (plants, animals including man as an organism—'physical man' and micro-organisms) is related to human geography (human beings, 'social man', 'economic man' and 'technological man'), chemistry (biochemistry) and biological or life sciences (botany-ecology, and zoology). The interactions and interdependence of abiotic and biotic components of biospheric system result in two types of ecosystems viz. (i) **biosystem,** and (ii) **ecobiosystem** or **geobiosystem**. The study of biosystem becomes the subject of biology while the study of geobiosystem becomes the subject matter of environmental geography-within the major fields of geography (fig. 1.2).

Since the interactions and mutual interdependence of abiotic and biotic components of the biosphere are studied in biology and environmental geography both and therefore it is necessary to differentiate these two disciplines though their boundaries are very much overlapping. Ordinarily, biology is concerned with 'organic matter' and is defined as the study of structural and functional characteristics of organisms (plants, animals and micro-organisms) or part thereof.

Traditionally, biology is divided on two bases viz. (i) on the basis of fundamental biological characteristics common to all life forms (plants, animals and micro-organisms). The common biological characteristics are morphology, physiology, evolution, genetics, ecology etc. On this basis the subdivisions of biology are morphological or structural biology, physiological biology or functional biology, developmental biology, ecology etc. Such division of biology is known as 'basic division', (ii) Biology is also divided on taxonomic bases into botany, zoology and micro-biology (study of micro-organisms). Each broad branch of biology can be further subdivided into smaller branches viz. zoology into entomology, protozoology etc. and botany into mycology, phycology etc. It is important to note that in the 'basic division' of biology 'ecology' is treated as one of the branches of biology whereas in 'taxonomic division' ecology is treated as one of the fundamental biological characteristics common to all life forms.

Modern subdivision of biology is based on 'levels of organisation of biological units which in short are termed as 'biotic levels' (fig. 1.3) common to all life forms. Gene, cell, tissue, organ and organism (individual) are lower order biotic levels which are common to all organisms. Several genes constitute a cell, a tissue is formed by hundreds and thousands of cells, several tissues constitute an organ and several organs make one organism, a complete biological system. On the other hand, organisms (group of plants, animals or micro-organisms), populations (group of individuals of any one kind of organism), communities (all of the populations occupying a given area) and biomes (system of homogeneous community units occupying a given region) are higher order biological units. The biological units of both lower and higher biotic levels are interrelated and interdependent among

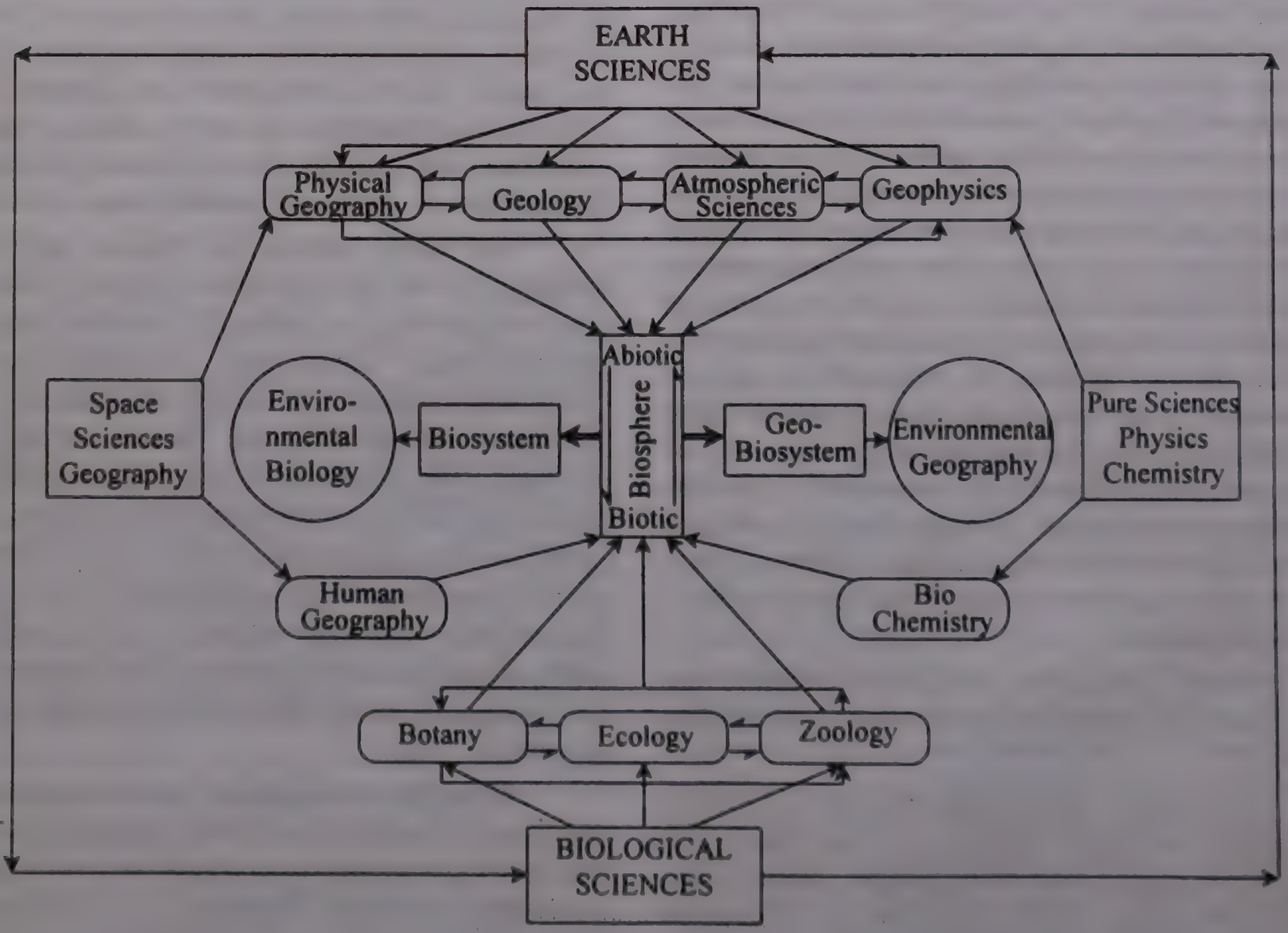
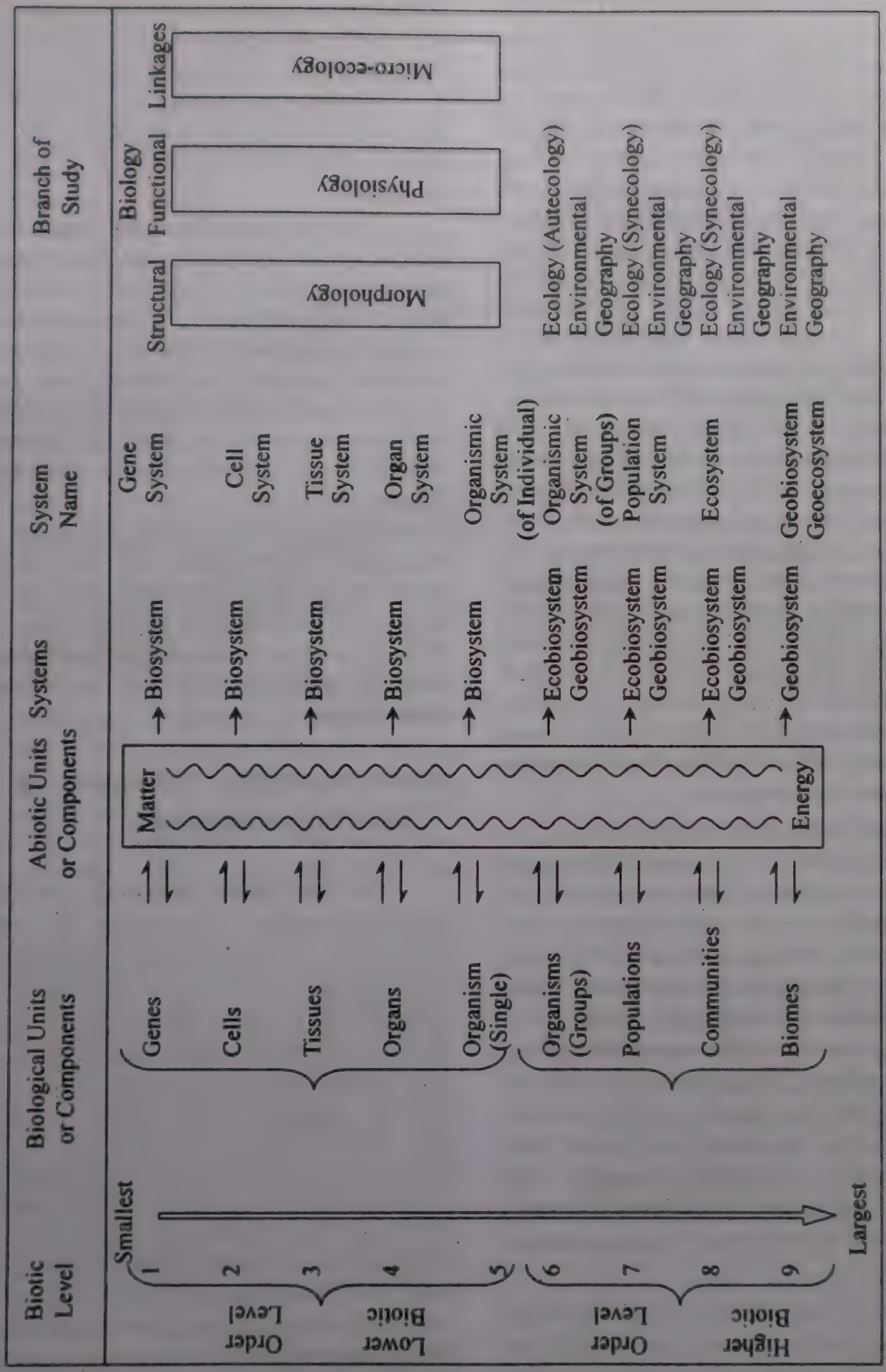

EARTH SCIENCES
Physical Geography
Geology
Atmospheric Sciences
Geophysics
Abiotic
Biosphere
Biotic
Space Sciences Geography
Enviro-nmental Biology
Biosystem
Geo-Biosystem
Environmental Geography
Pure Sciences Physics Chemistry
Human Geography
Bio Chemistry
Botany
Ecology
Zoology
BIOLOGICAL SCIENCES

Fig. 1.2 : Links between environmental geography and related fields of earth sciences, life sciences (biological sciences) and pure sciences.



Biotic Level	Biological Units or Components	Abiotic Units or Components	Systems	System Name	Branch of Study
Lower Order Biotic Level: 1 (Smallest)	Genes	Matter ⇄ Energy	Biosystem	Gene System	Biology: Structural – Morphology; Functional – Physiology; Linkages – Micro-ecology
2	Cells	⇄	Biosystem	Cell System	
3	Tissues	⇄	Biosystem	Tissue System	
4	Organs	⇄	Biosystem	Organ System	
5	Organism (Single)	⇄	Biosystem	Organismic System (of Individual)	
Higher Order Biotic Level: 6	Organisms (Groups)	⇄	Ecobiosystem Geobiosystem	Organismic System (of Groups)	Ecology (Autecology) Environmental Geography
7	Populations	⇄	Ecobiosystem Geobiosystem	Population System	Ecology (Synecology) Environmental Geography
8	Communities	⇄	Ecobiosystem Geobiosystem	Ecosystem	Ecology (Synecology) Environmental Geography
9 (Largest)	Biomes	⇄	Geobiosystem	Geobiosystem Geoecosystem	Environmental Geography

Fig. 1.3 Presentation of different biosystems resulting from the interactions between biological units (components) of different biotic levels and abiotic environment.

themselves as well as they are also interrelated through the exchange of matter and energy with their surrounding abiotic/physical environment.

The interactions of each biological units of lower biotic level with abiotic unit produce different 'biological system' or '**biosystem**' (Thienemann, 1939) e.g. gene system, cell system, tissue system, organ system and organismic system (individual organism) whereas the biological units of higher order biotic levels (organisms, populations, communities and biomes) are termed as **'ecological units'**. Thus the interactions of 'ecological units' with abiotic environmental components produce different higher order 'biosystems' which are in fact termed as **'ecobiosystem'** (which are named after the biological unit of a given biotic level of higher order e.g. organismic system involving groups of individuals, population system, ecosystem involving communities and geobiome system) whereas different higher order biosystems may be termed as **'geobiosystem'** in environmental geography, e.g. organismic geobiosystem', 'population geobiosystem', 'geoecosystem' and 'geobiome system'. Thus it may be summarized that the study of 'biosystem' of lower order biotic levels viz. gensystem, cell system, tissue system, organ system and organismic system (of a single organism) falls under the domain of biology wherein these are studied under three main branches of biology e.g. morphology or structural biology (study of structural or morophological characteristics of each biological unit of lower biotic level), physiology (study of functional linkages between structural components of each biological unit of lower biotic level) and microecology (study of interrelationships or functional linkages between biosystems of lower biotic levels and surrounding abiotic/physical environment).

The higher order biosystems known as ecobiosystems of higher biotic levels (organismic system, population system and ecosystem involving organisms, populations and communities respectively) are studied in ecology as branch of biology wherein the interrelationships of functional linkages between each ecobiosystem (of higher biotic level) and surrounding physical environment and among organisms are studied. The ecological study of geobiosystems involving spatial unit of various dimensions (e.g. local, continental and global) falls within the realm of environmental geography. The biological unit of the largest biotic level known as **biome** is exclusively studied in environmental geography.

Thus it may be concluded that environmental geography is benefitted by the information derived from the ecological studies of ecobiosystems of higher biotic levels as done in ecology, a branch of biology. It is thus obvious that ecobiosystems of higher biotic levels are studied in ecology where as geobiosystems are studied in environmental geography. Ecology is mainly concerned with the functional linkages between different ecobiosystems and their surrounding physical environment and among the organisms of a given ecobiosystem whereas environmental geography is concerned with the spatial attributes of such functional linkages at different spatial levels (local, regional, continental or global).

It may be pointed out that the term 'ecobiosystem' should not be confused with 'ecosystem' because ecosystem is that ecobiosystem which is produced only by the interaction of 'communities of species' (seventh biotic level) with physical environment. A biologist is mainly concerned with the study of structural and functional characteristics of biosystems of lower biotic levels (upto 5th biotic level), an ecologist is concerned with the study of functional linkages of ecobiosystems of higher biotic levels except of 8th order (biome), and an environmental geographer is concerned with the study of spatial organization of distributional patterns of interrelationships between biotic and abiotic components of different geobiosystems (of higher biotic levels) and between geobiosystems and technologically advanced man.

1.5. FUNDAMENTAL CONCEPTS IN ENVIRONMENTAL GEOGRAPHY

Environmental geography, as stated in the preceding section, is basically the study of total environment of the earth as a living planet having both physical and biotic components. The fundamental study unit of environmental geography is the life layer of the earth having atmospheric, lithospheric and hydrospheric components, which is responsible for the support of all types of life. This life supporting layer, very commonly known as biosphere, is characterised by the operation of several physical and biological processes, mutual interactions and interdependence of abiotic and biotic components of the biospheric ecosystem, production and consumption of ecological resources, various positive and negative responses of interactions between different components of the environment resulting into stability or instability of biospheric ecosystems at different levels (local, regional and global), environmental degradation and pollution arising out of increasing pressure of economic and technological man on the environment and man's renewed efforts and struggle to stabilise the disturbed ecosystem, to conserve and manage the ecological resources and to ameliorate environmental degradation and pollution through different pollution-control and abatement programmes. There are certain basic principles which govern the basic aspects of environmental geography viz. natural processes, both physical and biological in the life supporting layer (biosphere) and relationships between man and environment and man and environmental processes, integrated functional unit of the biotic and abiotic components of the environment (ecosystem), functioning of ecosystem, ecological evolution and succession, climatic changes and ecological modification, and environmental degradation and pollution arising out of human activities and ecological resources and their conservation and management.

The following principles and concepts of environmental geography may be identified.

1. Environmental system or ecosystem is the fundamental ecological unit for the study of environmental geography.

The planet earth is the only living planet that has atmosphere, environment and living organisms including plants, animals and micro-organisms. Since the environment is both physical and biological concept, it encompasses both the non-living (abiotic) and living (biotic) components of the planet earth.

Environment is a comprehensive term which in general refers to surroundings but in geographical perspective environment includes abiotic (physical-land, air and water) and biotic (plant and animals including man and his several functions, organisations and institutions) components of the life supporting layer-the biosphere. The earth is the only known planet having different kinds of life forms wherein there are complex sets of interrelationships between the physical and biological components. Various linkages between physical and biological components at different levels maintain the unity of the biospheric ecosystem.

Ecosystem is defined as a fundamental functional unit occupying spatial dimension of 'earth space ship' characterised by total assemblage of biotic community and abiotic components and their mutual interactions within a given time unit.' (Savindra Singh, 1991). The following are the basic properties of an ecosystem :

- Ecosystem of any given space-time-unit represents the sum of all living organisms and physical environment.
- It is composed of three basic components viz. energy, biotic (biome) and abiotic (habitat) components.
- It occupies certain well defined area on the earth-space ship (spatial dimension).
- It is viewed in terms of time unit (termporal dimension).
- There are complex sets of interactions between biotic and abiotic components (including energy component) on the one hand and between and among the organisms on the other hand.
- It is an open system which is characterised by continuous input and out put of matter and energy.
- It tends to be in relatively stable equilibrium unless there is disturbance in one or more controlling factors (limiting factors).
- It is powered by energy of various sorts but the solar energy is the most significant.
- It is a functional unit wherein the biotic components (plants, animals including man and micro-organisms) and abiotic (physical environment) components (including energy component) are intimately related to each other through a series of large-scale cyclic mechanisms viz. energy flow, water cycle, bio-geochemical cycle, mineral cycle, sediment cycle etc.
- Ecosystem has its own productivity which is the process of building organic matter based on the availability and amount of energy passing through the ecosystem. The productivity refers to the rate of growth of organic matter in an areal unit per time unit.
- Ecosystem has scale dimension i.e. it varies in spatial coverage. It may be as small as a cowshed, a tree or even a part of a tree having certain micro-organisms. The largest unit is the whole biosphere. Thus the ecosystems may he divided into several orders on the basis of spatial dimension. It is clear that 'the ecosystem is a convenient scale at which to

consider plants and animals and their interaction because it is more localised and thus more specific than the biosphere in its entirety, and it includes a sufficient wide range of individual organisms to make regional generalizations feasible and valuable' (C.C. Park, 1980).

- There are different sequences of ecosystem development. The sequence of ecosystem development in terms of a particular suite of physical and chemical conditions is called as **'sere'**. A 'sere' represents the development of a series of sequential successions starting from primary succession and culminating into the last succession in a sere as **'climax'** or **'climatic climax'** which is the most stable situation of an ecosystem. Thus, the study of ecosystem development may help in environmental planning from ecological point of view.
- Ecosystems are natural resource systems.
- Ecosystem concept is monistic in that environment (abiotic component), man, animals, plants and micro-organisms (biotic component) are put together in a single framework so that it becomes easy to study the patterns of interactions among these components.
- It is structured and well organised system.
- Ecosystem, for convenience, may be studied as a *'black box model'* by concentrating on the study of input variables and related output variables while the internal variables may be ignored to reduce the complexity.

2. The biospheric ecosystem is governed by discernible processes.

The dynamic evolving earth system in general and the biospheric system in particular are governed by discernible processes, both physical and biological. The physical or geological processes operate through a set of cycles, the broadest being geocycle. In fact, the endogenetic and exogenetic processes create different types of haabitats on the earth's surface for living organisms on the one hand and sometimes destroy the habitats on the other hand. The driving force of the endogenetic processes comes from within the earth. Endogenetic forces create different types of relief features of various magnitudes on the earth's surface e.g. submerged continental margins and islands (due to subsidence), raised continental margins and emerged islands (due to emergence), mountains (through orogenetic force), faults and lakes (through crustal fracture), faults (due to seismic activities), volcanic mountains, plateaus and plains (through vulcanicity), accreted oceanic crust and subducted continental margins (due to plate tectonics) etc. Exogenetic processes originate from the atmosphere and are engaged in continuous process of denudation of surface irregularities caused by endogenetic processes.

The interactions between endogenetic and exogenetic (denudational) processes lead to evolution of landscapes of cyclic nature. In other words, the evolution of landscapes on the earth's surface takes place in cyclic manner as presented by W.M. Davis and advocated by his contemporary and subsequent followers. If the principle of cyclic evolution of landscape is accepted, though majority of the present-day geomorphologists believe in non-cyclic nature of the development of landscapes (geomorphic system being in dynamic equilibrium), it certainly affects life forms in a particular region. For example, if a mountain having stable ecosystem characterised by 'climax vegetation' is eroded down to the base level under prolonged period of crustal stability, the very complexion of pre-existing mountain ecosystem will be entirely changed in terms of species and communities of plants and animals and new succession of vegetation would start and under uniform environmental condition the secondary succession of vegetation communities may lead to the attainment of new 'climax vegetation' and stable ecosystem which may be further disturbed and destroyed by fresh upliftment of plain ecosystem by orogenic or epeirogenetic movements and again new stable mountain ecosystem may be possible if uniform environmental conditions persist for fairly long period of time.

All these suggest cyclic nature of physical processes and their impacts on cyclic pattern of ecosystem development. This cyclic concept of landscape development by physical or environmental processes and their responses of cyclic development of ecosystem may be challenged on the ground that biotic communities may adjust with the changed circumstances caused by gradual transformation of mountain ecosystem into plain ecosystem but it may be pointed out that the biotic communities of higher altitudes cannot adjust themselves with the environmental condition of significantly lower altitudes and therefore replacement of species is a certainty.

3. There is continuous creation, maintenance, destruction and recreation of surface materials of the earth.

Various physical, chemical and biological processes are continuously engaged in the creation, maintenance, destruction and recreation of surface materials of the earth's surface (both organic and inorganic). The process involved in the creation of earth materials (inorganic) is know as 'geologic cycle' which includes a set of several sub-cycles e.g. the hydrologic cycle, the rock cycle, the geochemical cycle and the geotectonic cycle. The earth materials viz. minerals, rocks, soils, water etc. are not only created but are also maintained, changed in their properties, transferred from one place to another and even destroyed by geologic cycle but these materials even passing through the aforesaid pathways remain initially uncontaminated and are very useful for man. Whenever these materials are used or dispersed by man, they become contaminated and are seldom available for human use because either they are dispersed to such locations which may not be reached by man for fairly long period of time or they become so deformed and contaminated that they are not reusable. Sometimes, some renewable natural resources (for example water) are so contaminated that they become non-renewable.

The biogeochemical cycles comprising several subcycles circulate biochemical elements, commonly known as nutrients (most important being Oxygen-O, Carbon-C, Hydrogen -H, Nitrogen -N, Phosphorus-P and Sulpur-S), through circular routes, in various compartments (storage reservoirs) of the biosphere e.g. atmospheric compartment or storage reservoir, sedimentary compartment or storage reservoir. In other words, the cyclic pathways of the circulation of elements from inorganic phases to organic phases and again back to inorganic phase are collectively known as biogeochemical cycles. Thus the circulaiton of materials from different reservoirs of the inorganic phase through various pools of organic phase in the biosphere determines the size of different resrvoirs and pools on the basis of inflow-outflow ratio. When the inflow of materials in a pool (compartment or reservoir) equals the outflow of materials from the pool (compartment or reservoir), the concerned pool is in steady state. When such equilibrium is maintained at ecosystem level (equilibrium in all components of the ecosystem) this is called as ecosystem stability and such condition is very much useful for all organisms in general and mankind in particular.

It may be further pointed out that not all the chemical elements are circulated and cycled in perfect cyclic paths. For example, the chemical elements having gaseous phases (atmospheric reservoir) like carbon (C), oxygen (O), hydrogen (H) and nitrogen (N) tend to have more perfect rather complete and rapid recycling and are quickly regenerated and become available to biological activities. Such biogeochemical cycle is known as global gaseous cycle (having a series of independent and interdependent cycle such as carbon cycle, oxygen cycle, hydrogen cycle and nitrogen cycle). On the other hand, there are some elements having sedimentary phase (lithospheric reservoir) like phosphorus whose recycling is complex, less perfect and slow. Such biogeochemical cycle is known as sedimentary local cycle. The global gaseous cycle involves the whole of the biosphere and links the atmosphere with the biosphere but the sedimentary cycle operates at local and regional levels of ecosystems and is more susceptible to disruption by human activities.

The biological communities have affected and altered and continue to affect and alter the cycling of chemical elements/nutrients in the air, water and the soils so much so to sustain life on the earth but the emergence of man and gradual increase in his technological skills have largely disturbed the biogeochemical cycles which have resulted into depletion of certain natural resources at few places on the globe.

It is, therefore, necessary for environmental geographers to understand the basic principles of the functioning of physical/environmental and biological processes because these affect and control the life patterns in the life layer (biosphere).

4. Physical and biological processes operate according to the law of uniformitarianism.

Physical/environmental and biological processes operate according to the **law of uniformitarianism**. James Hutton's (Scottish Geologist) law of uniformitarianism having two basic principles of 'the present is key to the past' and 'no vestige of a beginning: no prospect of an end', postulated in 1785, and related to 'cyclic nature of earth's history' states that 'all the physical laws and processes which operate today, operated throughout geologic time, although not necessarily always with the same intensity as now'. In other words, the very nature of the operation of physical processes remains almost the same throughout geologic history of the earth though their frequencies and magnitude may vary. The same law of uniformitarianism of geologic evolution of the earth applies to the biological processes and biological evolution at least from the date of the origin of atmospheric oxygen and appearance of life on this planet earth. In other words, the biological processes which operate today might have operated in the past though with varying degree of relationships between biological communities and physical or natural environment and between organisms.

The Darwinian theory of origin of species involving the processes of **natural selection, adaptation and survival of the fittest,** almost conforming to the law of uniformitarianism is based on the following processes of natural selection :

- There are heritable variations in the individual species. Though each heritable variation is small but it is very significant because it forms the very basis of evolution of species.
- Heritable variations provide certain characteristics which become advantageous to some individuals to become more efficient and better able to survive in their environment for the struggle of their lives.
- Such advantageous characteristics conferred on an organism may provide better chance of survival and reproduction.
- When these advantageous characteristics are passed on by the organisms to their offsprings, the succeeding generations become superior and further efficient in the struggle for existence and survival.
- The individuals of species, which lack the advantageous characteristics to stand up to their environmental conditions in their struggle for life and existence, are most likely to be eliminated by competitions from the better equipped superior members (which have acquired advantageous characteristics) of their species.
- During the struggle for existence between organisms, the winner leads to evolution of species and the loser leads to extinction. This so happens when the struggle takes place between closely related species.
- The process of natural selection (as referred to above) and adaptation to environmental conditions lead to gradual modification and diversification of species over long period of time. Such variations in species increase progressively with each succeeding generation of species and evolution of species continues.

But D. Vries and many more opposed the Darwin's concept of **progressive evolution of species** and pleaded for abrupt speciation on the basis of mutation having the following basic elements as stated by T. Dobzhansky (1950) :

(i) 'The mutation process furnishes the raw materials of evolution'.

(ii) Numerous gene patterns are produced during the process of sexual reproduction.

(iii) 'The possessors of some gene patterns have greater fitness than the possessors of other (gene) patterns in available environment'.

(iv) The frequency of superior gene patterns is increased by the process of natural selection while the inferior gene patterns are suppressed.

(v) 'Groups of some combinations of proven adaptive worth become seggregated into closed gnetic system, called species.'

(Quoted by C.C. Park, 1980)

5. Natural environmental system is governed by homeostatic mechanism.

Physical and biological processes of the natural environmental system operate in such a way that any change in any part of the environment at any place in a specific time period is suitably compensated by **negative feedback mechanism** in a natural condition. Thus the natural environmental system has 'inbuilt self regulating mechasnim' known as **homeostatic mechanism** through which any change in the natural ecosystem/environmental system is counterbalanced by responses of the system to the change and ultimately ecosystem stability or environmental equilibrium is restored. In other words, any change in the environment brought by the natural processes is suitably compensated by changes in other components of the environment. Thus there is reciprocal relationship between various components of the environment. The physical processes create suitable habitats for biological communities on the one hand, biological communities (mostly man) modify the environment on the other hand.

In fact, life has continued to modify and alter the atmospheric, lithospheric and oceanic components of the natural environment since the very beginning of life on this planet earth. The very nature of the atmosphere, the rocks and sediments, freshwater on the earth's surface and oceanic water in terms of organic and inorganic constituents has been greatly modified by the organisms including both plants and animals. Since the dawn of industrial revolution man has emerged the most powerful environmental process spearheaded by modern technologies capable of modifying the environment to great extent. In fact, of all the organisms man is the most intelligent and powerful animal and is capable of not only affecting the environment like other organisms but is also able to alter the basic composition of the environment at a scale detrimental not only to all biota but also to his own existence. Phenomenal increase in human population in the present century has put enourmous pressure on natural resources which has resulted into accelerated rate of rapacious exploitation of natural resources in order to meet out the demand of everincreasing population, rapidly growing industries and increasing urbanization. The development of modern technologies and increased economic functions of man have further accelerated the rate of exploitation of natural resources. All these have modified a few of the components of the environment to such an extent that the adverse effects on the environment cannot be set right by the **homeostatic mechanism** or self regulatory mechanism of the environment. Consequently, the changed environmental conditions adversely affect the organisms (both plants and animals including man) in the biosphere. Thus it is obvious that **environmental degradation** refers to the deterioration in its physical components brought in by the biological processes mainly by human activities to such an extent that it cannot be set right by the self regulatory mechanism or homeostatic mechanism of the environment.

Man affects biological processes directly and indirectly. 'From a biological point of view, we also know, that the ultimate fate of every species is extinction' (D.B. Botkin and E.A. Keller, 1982). Direct impact of man on biological processes through purposive elimination of some species, domestication of some species and inadvertent increase of some species changes the rate of extinction of species and alters the balance of population of species in a given region. The increased land use changes mainly through the conversion of more and more natural ecosystems into agricultural land and urban complexes and industrial landscapes consequent upon phenomenal growth in numan population have been responsible for extinction of a few species due to resultant adverse effect on ecological conditions of the region concerned. In fact, there has been parallel rise in human population and extinction of species of plant and animal communities. Thus it is of fundamental significance to study the present stage of operation of natural and biological processes in the light of interference of man through his economic activities so that the rate of changes of both natural and biological processes may be predicted and alternative strategies for environmental and ecological management may be formulated. It is also significant to point out that catastrophic natural processes like violent volcanic eruptions and outflow of immense volume of lava, widespread global climatic changes etc. would continue to eliminate some species of plants and animals, leading to extinction of species. But such situation also leads to the evoltution of new species.

6. There is reciprocal relationship between abiotic and biotic components of the natural environmental system.

There is reciprocal relationship between biotic and abiotic (physical) components of the environment. The physical processes create suitable habitats for biological communities on the one hand, biological communities (mostly man) modify the environment on the other hand. In fact, life has continued to modify and alter the atmospheric, lithospheric and oceanic components of the biosphere since the very beginning of life on this planet earth. The very nature of the atmosphere, the rocks and sediments, fresh water on the earth's surface and oceanic water in terms of inorganic and organic constituents has been greatly modified by the organisms including both plants and animals. Since the dawn of industrial revolution in 1860 man has emerged as the most powerful environmental process spearheaded by modern technologies to modify the environment. Environmental geographers besides studying the mode of operation of environmental and biological processes must understand the nature of mutual interactins between environmental and biological processes before undertaking any programme of conservation of ecological resources and environmental management. In this regard particular attentions must be paid towards the understanding of man-environment relationship with ecological approach and various ways of modification and alteration of environmental processes by man and the consequent responses of such modifications of environmental processes of total environment.

The environment affects man through (1) biophysical limitations, (2) behavioural controls, and (3) resource availability. Biologically, human body can function properly only in certain suites of environmental conditions in terms of oxygen, heat (sunshine), light, humidity and precipitation, wind, lightning, fog, clouds, atmospheric electricity and space. Even the survival of human body depends on above factors. Various combinations of environmental factors have not only affected but conditioned racial characteristics in different parts of the earth's surface. Environment also influences and conditions thoughts, ideologies and culture of human being. Most significant aspect of the environment influencing human activities is the availability of resources. The richness or poorness, quality and quantity and above all the availability of natural resources decide the type of human activities, economic variability, social organizations, political stability, international relations etc.

If we look at historical progression of man-environment relationships it becomes clear that purely natural relationship between **'physical primitive man'** and natural environment during prehistoric period has changed to hostile relationship between **'technological man'** and the environment at present. This substantial change and shift in the nature and magnitude of man's interactions with the natural environment has given birth to numerous environmental problems of serious consequences because the changes effected by man in the environment have become unadjustable by the inbuilt self requlatory mechanism of the natural environmental system/ecosystem. The study of changing relationships between man and environment in historical perspective may help in demonstrating the increasing adverse impacts of human activities on the environment.

Ecological approach to the study of man-environment relationships is based on the basic principle of ecology which is the study of mutual interactions between organisms and physical environment on the one hand and interactions among the organisms on the other hand in a given ecosystem. Thus, man is considered as an integral part of nature/environment. The relationship of man 'with the natural environment should be symbiotic and not exploitative nor suppressive' (C.C. Park, 1980). This school recognises man, being most skilled and intelligent, as the leader of all biota and steward of the earth. This approach further lays emphasis on wise and restrained use of natural resources, application of appropriate environmental management programmes, policies and strategies keeping in view the ecological principles so that already depleted natural resources are replenished (wherever possible), degraded environment is set right and ecological balance is maintained.

It may be pointed out following C.C. Park (1980) that man-environment relationships and debate should be viewed taking into account the multi-dimensional aspects of environmental problems which are the result of complex series of several factors viz. physical, economic, social, political, ethical etc. but any positive approach adopted for the study of man-environment relationships must take into account the fact that there should be harmony and not hostility between man and environment. It is obvious that the relationship between man and environment is two-directional as the environment affects and influences man and in turn man also influences and modifies the environment. This type of mutual interaction and relationship between man and environment is symbiotic in character.

7. The energy flow and circulation of nutrients in the biospheric ecosystem help in the sustenance of life on the planet earth.

The natural ecosystems are open systems characterised by continuous input of energy (solar radiation) and matter (nutrients) and output of energy and matter and they tend to be in relatively stable equilibrium unless there is disturbance in one or more controlling factors (limiting factors). The most significant source of energy is solar radiation which is trapped by the autotrophic green plants and is converted into heat energy through the process of photosynthesis. The energy flow is unidirectional as the energy lost through various organic components of the ecosystem at different trophic levels is not again available for use in the ecosystem. There is a progressive loss of energy by respiration of organisms through increasing trophic levels. The nutrients are circulated in the ecosystem through several cyclic pathways collectively known as 'biogeochemical cycles'.

As described earlier the biosphere is the largest ecosystem. There is input of matter and energy in the ecosystem to build biological structure, to reproduce and to maintain necessary internal energy level so that the ecosystems may function properly. There is also export of matter and energy from the ecosystems. When there is balance between the input of matter and energy and output (exit) of matter and energy, the ecosystems tend to be in equilibrium state. All organisms in the biosphere are like machines because they use energy to work and convert one form of energy into another form of energy. The energy pattern and flow are governed by the first and the second laws of thermodynamics.

All sources of energy of the biospheric ecosystem are virtually out side the biosphere. The major source of energy is the solar radiation and other minor sources of biospheric energy are cosmic radiation, geothermal energy and energy subsidies released from storage in fossil fuels. The sun is the most important source of energy for the proper functioning of the ecosystem because the solar radiation is converted by green plants into food or chemical energy through photosynthesis which is used by plants themselves, animals and man. Solar radiation also helps directly and indirectly in the circulation of matter in the biospheric ecosystem (the process is called as biogeochemical cycles comprised of water or hydrological cycle, chemical elements cycles, sediment cycle etc.).

The energy flow and circulation of nutrients help in the sustenance of life on the planet earth. It is significant to point out that 'sustained life on the earth is a characteristic of ecosystems, not of individual organisms of populations', (D.B. Botkin and E.A. Keller, 1982). That is to say that all the organisms are interdependent in terms of production and consumption of food and recycling of organic and inorganic matter. For example, autotrophic green plants are the primary producers upon which depend all of the organisms directly or indirectly for their food but the primary producer autotrophic plants cannot decompose their dead organs. Similarly, micro-organisms do not produce their own food themselves but decompose dead organisms as well as their waste materials and receive their energy and chemical nutrition from the dead organisms. Thus it is apparent that efficient and complete recycling of nutrients in the various components of the ecosystems may be possible only when there are several species. This aspect, ecosystem diversity and complexity in terms of species, reflects the stability of the ecosystems.

The circulation of elements or matter or nutrients (both organic and inorganic) in the biosperic ecosystem is made possible through energy flow. In other words, energy flow is the main driving force of materials (nutrients) circulation in the various biotic components of the ecosystem (the biosphere). The organic and inorganic substances are moved reversibly in the biosphere, atmosphere, hydrosphere and lithosphere through various closed system of cycles 'collectively known as geobiochemical cycles', in such a way that total mass of these substances remain almost the same and these substances are always available for use by the biotic communities. "In other words, the materials, that make up the biosphere are distributed and redistributed by means of an infinite series of cyclic pathways motored by the continuous input of energy". (P.A. Furley and W.W. Newey, 1983).

8. There are temporal and spatial variations in species.

There are temporal and spatial variations in species. The Darwin's theory of evolution of species states that there is progressive evolution of species through the processes of natural selection and adaptation to environmental conditions which lead to gradual modification and diversification of species over a long period of time. Such variations in species increase progressively with each succeeding generation of species and evolution of species continues. Some alternative processes of evolution of species have been suggested e.g. mutation process (spontaneous evolutionary change in species) and reproductive isolation of morphologically differentiated population of species.

'Individual populations are capable of rapid exponential growth, but this is rarely achieved in nature, control of the population is the norm' (D.B. Botkin and E.A. Keller, 1982). This principle is very commonly known as 'homeostatic mechanism'. For example, if the population of certaion insects in a specific area increases exponentially beyond the optimal level, the food supply would fall short of demand of increased insect population resulting into strong competition among the insects for food and consequent deaths of several insects and decrease in insect population. Such self regulatory control of population is termed as **'density- dependent population control'**. In other words, density-dependent population control implies self regulation of population of species due to decrease in birth, survival and growth rates and phenomenal increase in death rates. Besides, population of species is also controlled by such factors which are not related to the birth, survival, growth or death rates or population size of species. Such factors are extreme events like severe atmospheric storms which destroy the trees. Such population control is termed as **'density-independent population control'**. Thus it may be summarized that 'nothing can increase forever. The earth and the known universe are finite in space, matter and energy. In a finite universe, there is an upper bound to the size of every thing. So too, are populations limited to a finite range' (D.B. Botkin and E.A. Keller, 1982).

The study of life forms in terms of their spatial distribution, temporal variations (evolution), dispersal and extinction at regional and global levels helps in identifying the advantages and disadvantages of adaptation of certain species by man in different localities for his own purposes. In other words, one can decide, while introducing and transporting exotic species to those areas which have never been native places of such species, what kinds of species would be useful for mankind of the area concerned. Similarly, disastrous species may be identified and their introduction in new areas may be safely avoided. This aspect of environmental geography may prove very useful in natural resource management if the behavioural aspects of biological communities in relation to their reproductive characteristics as determined by the natural environment of the concerned ecosystem are properly studied and the findings are given due weightage in the planning process but till now this aspect has always been ignored.

9. Ecosystem diversity and complexity enhances and maintains ecological stability .

The stability of ecosystem refers to balance between production and consumption of each element in the ecosystem. In other words, ecosystem stability means balance between input and output of energy and normal functioning of different biogeochemical cycles and stable condition of concentration of all elements. *T.D. Brock* (1967) has defined steady-state condition in mature ecosystem as 'a time-independent condition in which production and consumption of each element in the system are exactly balanced, the concentration of all elements within the system remaining constant, even though there is continual change' (Brock, 1967).

Ecosystem or ecological stability is viewed in different ways e.g. (i) Stability being viewed as constancy of species numbers within a natural ecosystem or the constancy of individual numbers of species within a population. Such stability has been termed by *M.J. Dunbar (1973)* as **'no-oscillation stability'**, (ii) Stability of a natural ecosystem is viewed in terms of system's capacity to withstand changes brought in the system by external factors and to maintain or return to its original state after external change. Such stability has been termed by H.A. Regier and E.B. Cowell (1972) as **'stability resistance'**. (iii) Stability has been interpreted by A.R. Hill (1975) as a resilience of system to adjust to stresses brought in the ecosystem. This is called as **'resilience stability'**. (iv) **Elastic stability** refers to the establishment of stability in a natural ecosystem after large-scale disturbances or perturbations. (v) **Cyclical stability** refers to the adjustment of a system to regular external changes. There is no unprecedented disturbance or perturbation.

The natural, *'normal* or *'uneventful'* ecosystem attains its steady state or equilibrium condition through **homeostatic mechanisms.** There is inbuilt self-regulating mechanism in a natural ecosystem through which any change in the ecosystem is counterbalanced by responses of the system to the change and ultimately ecosystem or ecological stability is restored. For example, if there is sudden change in the ecosystem (due to any external factor) like rapid increase or decrease in the population of a species and if this change is regulated and the population returns to its normal position through self regulating mechanisms within the system and the system returns to stability, these self regulating mechanisms are called as homeostatic mechanisms. This may be further explained with an example. If the population of insects in a specific area increases significantly beyond optimum level due to favourable climate, the food supply falls short of the demand of increased insect population. With the result there is competition among the insects for food and many insects die of starvation and thus the insect population is brought back to its original size and stability is restored.

The **'diversity/stability theory'** of ecosystem or ecological stability states that ecosystem diversity and complexity enhance the stability of population in a given system. This has been illustrated in a variety of ways by different scientists e.g. (i) according to C.S. Elton (1958) increase in the diversity of food webs promotes ecosystem stability because increased food web diversity increases the resilience of the system to outside invasions of exotic organisms and reduces the fluctuation in the population within a given ecosystem. (ii) Following R.H. MacArthur (1955) the ecosystem stability increases with increase of number of links in the food web because a large number of interacting feeding links provides alternative channels for energy flow and thus is generated a wide variety of adjustments of the population to environmental changes and stresses within the ecosystem. (iii) E.P. Odum has related high species diversity of a mature ecosystem representing a 'climax community' to more stability of a natural ecosystem because as the community succession operates, the homeostasis increases due to more protection available to the members of the community against external environmental change.

There are two models of the nature of ecosystem equilibrium. The **equilibrium model** states that an ecosystem always tends towards stability. Whenever the community of an ecosystem is disturbed due to external environmental change, it quickly returns to original state whereas the **non-equilibrium model** states that ecosystem stability is rarely attained because disturbances caused by frequent external environmental change do not allow to develop ordered state of species assemblages in an ecosystem.

Ecosystem instability refers to that state when an ecosystem is unable to adjust with environmental changes. This so happens when the changes are continuous and enormous and these changes exceed the resilience or capacity of the ecosystem. For example, rapid rate of mass felling of trees in a forest ecosystem seldom allows regeneration of forest community because exposed surface due to deforestation is subjected to intense weathering and erosion and nutrients are washed out by surface runoff. Himalayan forest ecosystem is a typical example of ecosystem instability because mass deforestation and subsequent grazing have resulted into complete removal of forests at certain localities.

The factors responsible for ecosystem stability or instability should always be viewed in terms of ecosystem resilience. If the environmental changes exceed the ecosystem resilience, ecosystem instability is caused but when the ecosystem resilience is such that it can withstand the environmental changes, ecosystem stability is maintained. The environmental changes which are responsible for ecosystem instability are both natural ones (climatic change, for example) or man-induced. Man causes ecosystem instability by (i) destroying completely or partly the natural vegetation or original animal species or by replacing them by other vegetation or animals, (ii) by introducing exotic plants or animals to any area where such biotic communities were not present previously, (iii) by altering or modifying one or more components of physical environment (land use changes, for example), (iv) by introducing foreign substances through the use of pesticides and herbicides, (v) by increasing or decreasing the original proportion of atmospheric gases, (vi) by manipulating environmental processes etc. Many of these environmental changes have been discussed in the 3rd chapter on 'Man-Environment Relationships' and in the 15th chapter on 'Man and Environmental Processes'.

10. The nature of human interactions with environment determines latter's stability or instability.

It has already been stated earlier that there is reciprocal relationship between man and environment. In order to enhance the quality of life of both, the environment and humans, there should be symbiotic relationship i.e. harmonious and friendly relationship as the environment provides habitats of varying kinds for different life forms and affects life style of various organisms in different suites of habitats having distinct assemblages of land, water, soil and climate, in turn organisms affect and modify the environment. This sort of mutual relationship makes the natural ecosystem more efficient. Of all the organisms man is the most intelligent and powerful animal and is capable of not only affecting the environment like other organisms but also altering the basic composition of the environment at a scale detrimental not only to all biota but also to his own existence. Phenomenal increase in human population in the present century has put enormous pressure on natural resources which has resulted into accelerated rate of rapacious exploitation of natural resources in order to meet out the demand of ever increasing population, rapidly growing industrialisation and urbanisation. The development of modern technologies and increased economic functions of man have further accelarated the rate of exploitation of natural resources. All these have contributed to the depletion or near depletion of a few precious non-renewable resources, degeneration of renewable resources (e.g. forest, grassland, surface and groundwater etc.), environmental degradation and pollution at local, regional and global levels and above all ecological crisis. The basic aim of environmental geography is to stress upon symbiosis between man and the environment so that harmonious relationship may be established which may lead to the welfare of human society.

It is, therefore, imperative for environmental geogapers to study the direct and indirect impacts of human activities on environmental/physical and biological processes leading to ecosystem instability and environmental degradation and pollution, the capacity and mechanism of natural/physical processes to absorb and adjust with the changes brought by man in the natural environment and make sincere efforts for the identification and determination of levels of environmental degradation, pollution and ecological imbalance at different spatial and temporal scales, for identifying real ecological and environmental crises, for the preparation of inventory of existing ecological resources, for the formulation of pollution control programmes and conservation and management of natural resources taking the fact into mind that all the resources even renewable and nonconventional (even the solar energy is also finite because the life of the sun is also fixed) are finite and we have moral obligation to our future generations.

2

THE ENVIRONMENT

2.1 MEANING OF ENVIRONMENT

The word 'environment has been derived from the French word **'environner'** meaning to encircle or to surround. The dictionary meaning of the word 'environment' is a surrounding; external conditions influencing development or growth of people, animals or plants; living or working conditions etc. This involves three questions-what is surrounded?, by what surrounded? and where surrounded? Decidedly the answer to the first question is living object in general and man in particular. If man is taken to be surrounded, physical attributes become the answer to the second question which becomes environment and where surrounded is the space or habitat. 'Primarily, the concern of all geographers is with the environment of man. But man cannot exist or be understood in isolation from the other forms of life and from plant life' (A.N. Strahler and A.H. Strahler, 1976, p. 4) and so environment of all biological population should be the concern of geographers. 'Environment refers to the sum total of conditions which surround man at a given point in space and time' (C.C. Park, 1980, p. 28). In the beginning the environment of early man consisted of only physical aspects of the planet earth (land, air and water) and biotic communities but with the march of time and advancement of society man extended his environment through his social, economic and political functions.

Generally speaking the environment is equated with nature wherein physical components of the planet earth viz. land, air, water, soils etc. support and affect life in the biosphere. A. Goudie (1984) in his book 'The Nature of the Environment' has, in fact, taken environment as the representative of physical components of the earth wherein man is an important factor affecting the environment. Environment is defined more comprehensively by others 'as a holistic view of the world as it functions at any point of time, with a multitude of spatial elemental and socio-economic systems distinguished by quality and attributes of space and mode of behaviour of abiotic and biotic forms' (K.R. Dikshit, 1984). He further remarks, 'the definition, and in turn the scope, could be governed by our concern and priorities. Our immediate concern is the quality of space we live in, the air we breathe, the food we eat, the water we drink and the resources we draw from the environment to support our economy' (K.R. Dikshit, 1984). He has also pleaded for the inclusion of only 'air-land-water-plant' in the concept of environment, thus excluding man and human society from the ambit of environment.

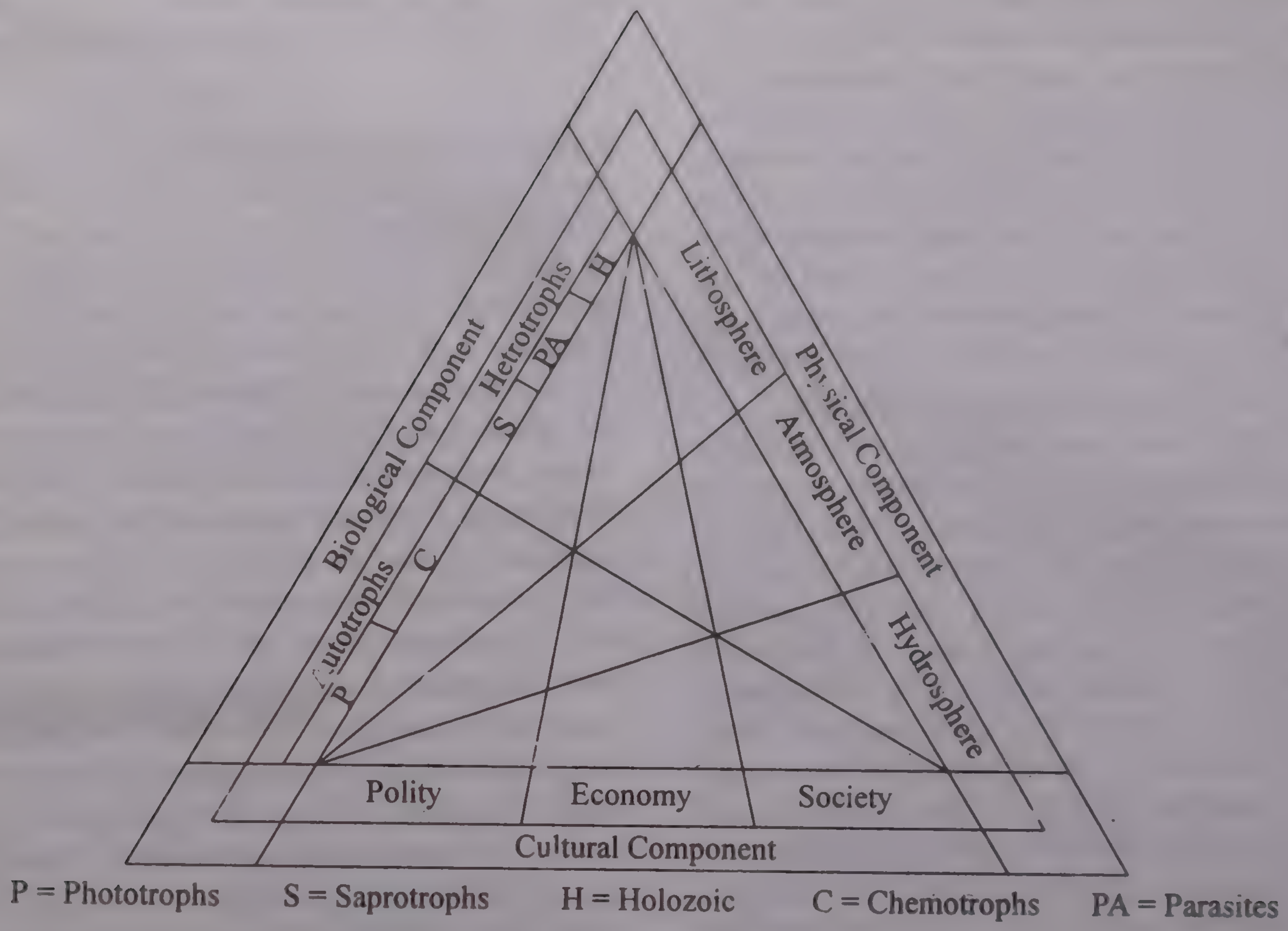

Biological Component
Autotrophs
Hetrotrophs
P
C
S
PA
H
Lithosphere
Atmosphere
Hydrosphere
Physical Component
Polity
Economy
Society
Cultural Component
P = Phototrophs
S = Saprotrophs
H = Holozoic
C = Chemotrophs
PA = Parasites

Fig. 2.1 : Elements of environment and their interactions (after Savindra Singh and A. Dubey 1983).

In fact, environment is viewed in different ways with different angles by different groups of people but it may be safely argued that 'environment is an inseparable whole and is constituted by the interacting systems of physical, biological and cultural elements (fig. 2.1) which are interlinked individually as well as collectively in myriad ways. Physical elements (space, landforms, water bodies, climate, soils, rocks and minerals) determine the variable character of the human habitat, its opportunities as well as limitations. Biological elements (plants, animals, micro-organisms and man) constitute the biosphere. Cultural elements (economic, social and political) are essentially man-made features which go into the making of cultural milieu' (Savindra Singh and A. Dubey, 1983).

Thus, environment is defined as '(1)The circumstances and conditions (physical conditions) that surround (and affect) an organism or group of organisms, or (2) the social and cultural conditions that affect an individual or community. Since human inhabit the natural world as well as the 'built' or technological, social, and cultural world, all constitute parts of our environment' (W.P. Cunnigham and M.A. Cunnigham, 2004).

2.2 STRUCTURE AND TYPES OF ENVIRONMENT

Since the environment is both physical and biological concept, it encompasses both the non-living (abiotic) and living (biotic) components of the planet earth. Thus on the basis of basic structure the environment may be divided into two basic types e.g. physical or abiotic environment and biotic environment. On the basis of physical characteristics and state, abiotic or physical environment is subdivided into three broad categories viz. (i) solid, (ii) liquid and, (iii) gas which represent the lithosphere (solid earth), the hydrosphere (water component) and the atmosphere respectively. Thus the three basic divisions of physical environment may be termed as (i) lithospheric environment, (ii) atmospheric environment and (iii) hydrospheric environment. These may be further brocken into smaller units based on different spatial scales e.g. mountain environment, plateau environment, plain environment, lake environment, river environment, maritime environment , glacier environment, desert environment, coastal environment, etc.

The biotic component of the environment consists of plants (flora) and animals (fauna) including man as an important factor. Thus the biotic environment may be divided into floral environment and faunal environment. All the organisms work to form their social groups and organisations at several levels and thus is formed social environment wherein the organisms work to derive matter from the physical environment for their sustenance and development. This process generates economic environment. It may be pointed out that of all the organisms man is the most skilled and civilized and hence his social organisation is most systematic. It is significant to note that three aspects of man e.g. physical, social and economic, have different characteristics and functions in the biotic environment as *'physical man'* is one of the organismic populations or biological community and thus requires basic elements of the physical environment viz. habitat (space), air, water and food like other biological populations and releases wastes into the ecosystem; *'social man'* establishes social institutions, forms social organisations, formulates laws, principles and policies to safeguard his existence, interest and social welfare and *'economic man'* derives and utilises resources from the physical and biotic environments with his skills and technologies. These may be termed as physical, social and economic functions of man. It is the third function (economic) which makes the man an environmental/geomorphic process as well because he transports matter and energy from one component of the ecosystem to the other. This aspect/function does not necessarily involve change in the working of the ecosystem so long as the exploitative functions are in harmony with the natural environment but when these exceed the critical limit, the equilibrium of the environment/ecosystem is disturbed and several environmental and ecological problems crop up which become detrimental not only to man himself but to whole population (of species) in a given ecosystem.

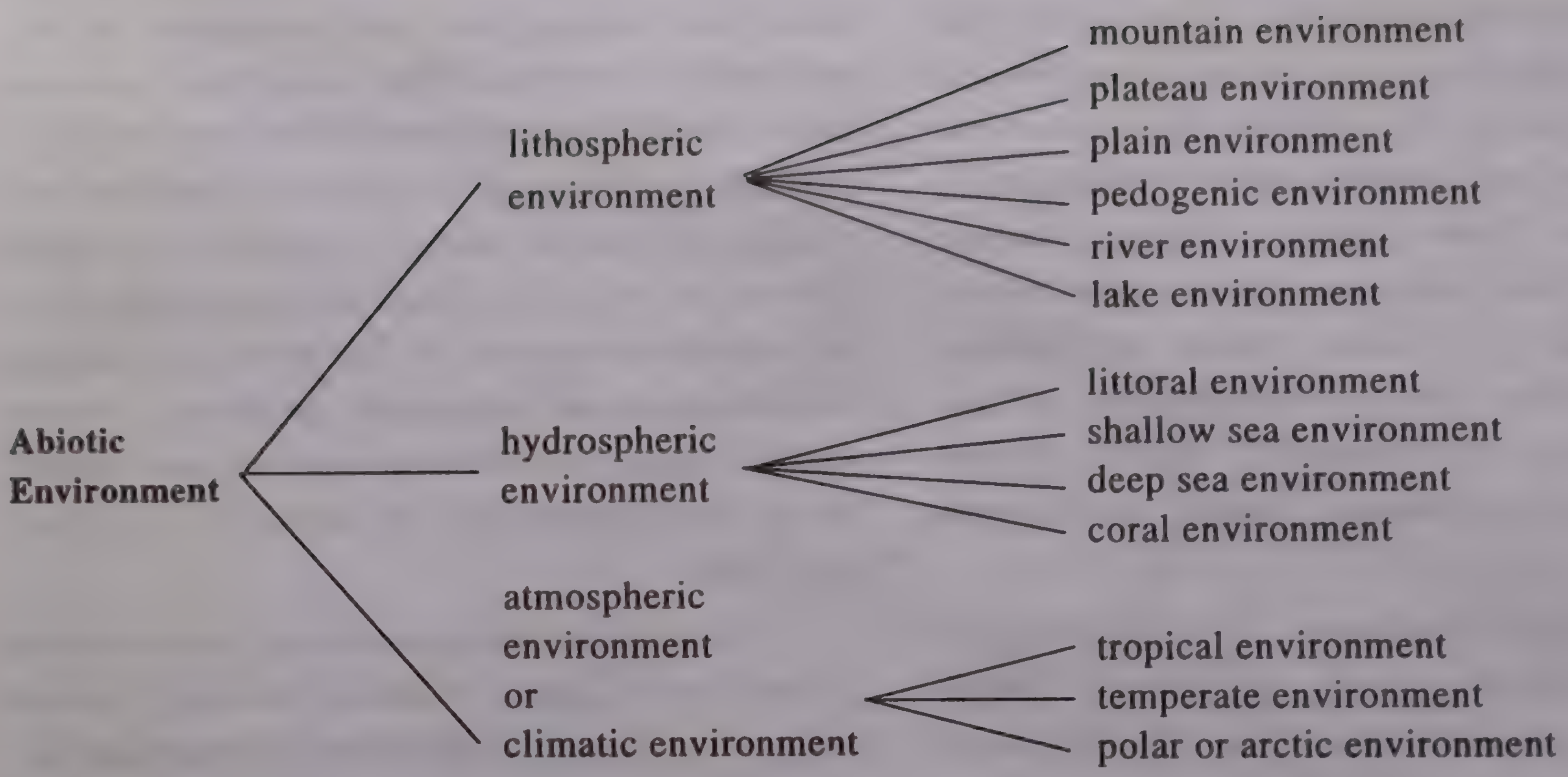
The physical environment may also be viewed in terms of climatic conditions providing certain suites of habitat for the biological communities viz. tropical environment, temperate environment, polar environment etc. which may be further sub-divided into smaller but specific divisions. Physical/abiotic and biotic environments fused together form 'biome environment' like tundra biome, temperate biome and tropical biome which are further subdivided into second and third order biomes. In environmental geography the physical environment is the most outstanding feature and thus should be given more significance than the social or cultural environment. The economic function of man becomes more significant than his other functions as it is more concerned with the functioning of ecosystem. Thus, the interaction of man through his economic functions and hence as an environmental process, with natural environment and resultant human response to the environment is the fundamental concern of environmental geography.

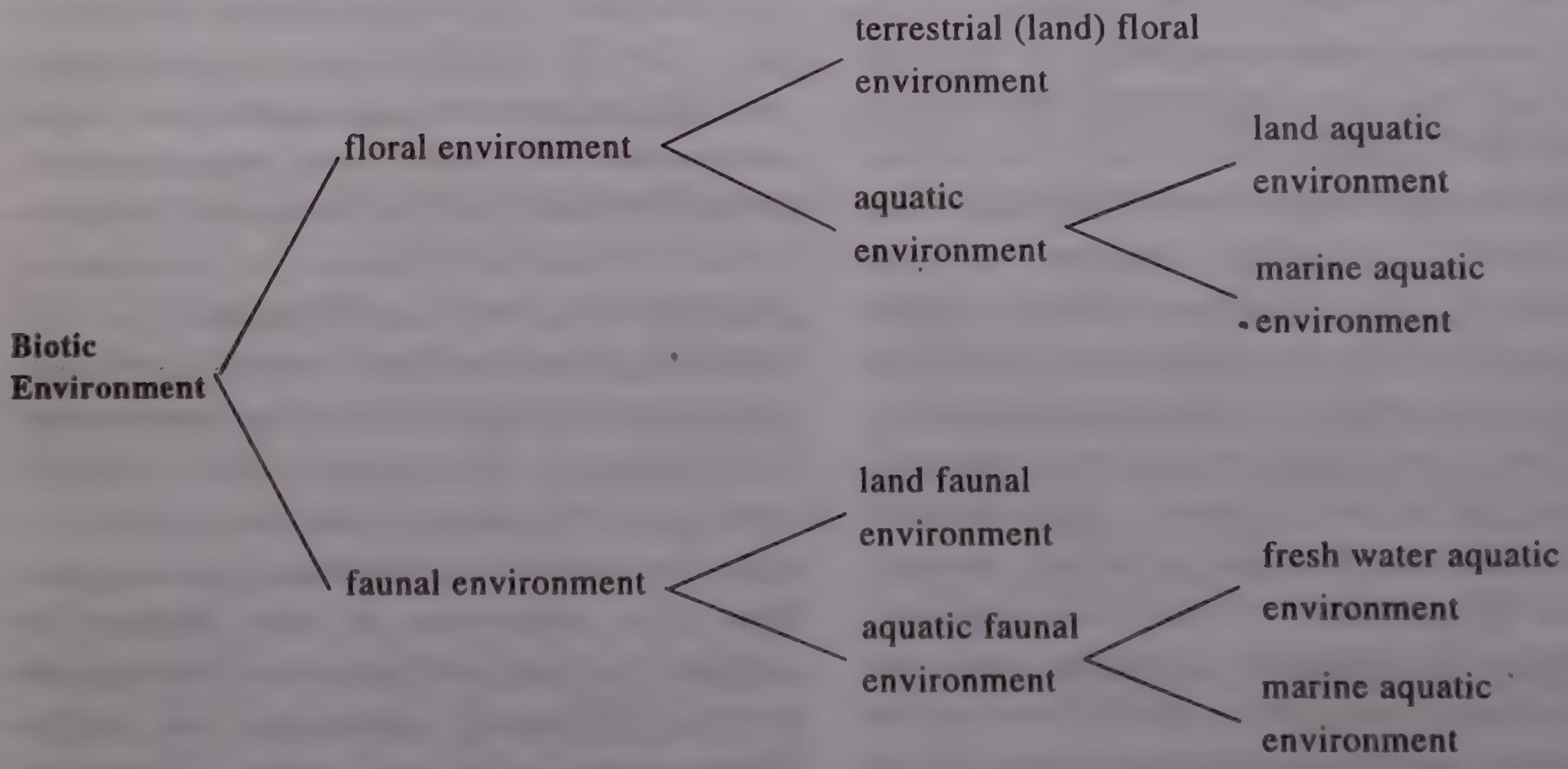
The classification and types of environment may be summarized as follows :

On the basis of major components

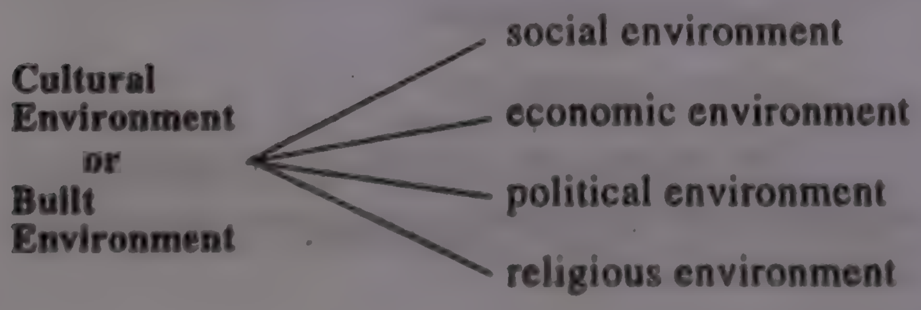
- abiotic environment
- biotic environment

The abiotic environment is further divided and subdivided on the basis of secondary and tertiary components as follows :


Abiotic Environment
lithospheric environment
mountain environment
plateau environment
plain environment
pedogenic environment
river environment
lake environment
hydrospheric environment
littoral environment
shallow sea environment
deep sea environment
coral environment
atmospheric environment or climatic environment
tropical environment
temperate environment
polar or arctic environment


Biotic Environment
floral environment
terrestrial (land) floral environment
aquatic environment
land aquatic environment
marine aquatic environment
faunal environment
land faunal environment
aquatic faunal environment
fresh water aquatic environment
marine aquatic environment

Man constitutes biotic components of the environment wherein man has created many new components collectively known as social or cultural components which altogether make 'built environment'. Thus, 'built environment' or cultural environment is subdivided as follows :


Cultural Environment or Built Environment
social environment
economic environment
political environment
religious environment

2.3 COMPONENTS OF ENVIRONMENT

Environment, as stated above, consists of three basic components viz. (i) abiotic or physical component; (ii) biotic components, and (iii) energy component. Physical or abiotic component consists of atmospheric component, lithospheric component and hydrospheric component while biotic component comprises plant component, animal (including man as physical man) component and micro-organismic component. Energy component includes solar energy and geothermal energy. These components have been discussed in the 6th chapter of this book.

The cultural environment comprises social component, economic component, political component, etc.

The various components of the environment may be summarized as follows :

Compoents of Environment

- abiotic components → land, air, water and soils
- energy components → solar and geothermal energy
- biotic components → plants and animals
- cultural environment → society, economy and polity

2.4 GEOGRAPHY AND ENVIRONMENT

Is environment a geographer's forte? The answer to this question would have been more positive and the tall claim that 'no discipline can boast of richer heritage of the study of the man-environment syndrome than geography' (J. singh, 1984) would have become more meaningful had the futile debate of 'determinism (environmentalism)-possibilism-probabilism' not prologned for long time and had much time and labour not been devoted for abstract locational analysis and atrophied spatial analysis (J. Singh, 1984) at the cost of physical aspect of geography rather the core of geography. The banner of environment/ecosystem/ecology would have not been carried away by natural sciences had the pitfalls of earlier geographers in dealing with environment been removed properly and indepth study of environment would have been developed step by step. The over-dominance of geography by cultural/human geography bemused by mild intoxication of 'faith in technological man's capacity to create resources and take care of environmental degradation' and 'locational analysis and spatial organisation models spearheaded by quantitative techniques' (J. Singh, 1984) drifted geographers away from the hard core physical and biogeography which landed geographers in deep slumber as the study of environment is concerned and they could wake up only when the issue of environmental degradation and ecological imbalance was over taken by the ecologists and other natural scientists by the end of 1960's. But these comments do not negate the close association of environment with geography because 'since the hey-day of determinism changing to the study of landscape and the subject's reorientation to spatial organisation geographers were always concerned with environment and it remained a basic element in most of the approaches' (K.R. Dikshit, 1984).

Right from the beginning 'man and the land', 'man and the nature', 'man's relationships to his earthly environment' etc. have been the recurring themes of geography irrespective of the dichotomy of 'earth made man' versus 'man made the earth'. Whether visible or not the concept of ecosystem and emphasis on environments have been always lurking in the background but the approach has been too fragmentary and hardly any composite picture of environment emerged. 'Obviously, the objective was never to understand the environment but to make use of it for demonstrating its role in emerging cultural landscape or the regional diversities' (K.R. Dikshit, 1984) and elements of physical environment like topographic characteristics, climate, soils etc. were taken as physical or geographical factors to explain variable distribution of matter in general and human population in particular over space; location of industries etc. It may be emphasised that the study of environment has always been associated with geography but with varying levels of significance during successive phases of methodological development of the subject. It may also be stressed that the environmental studies were based on much more generalisation and assumed relationships involving secondary data and information rather than on in-depth study of different components of environment based on empirical studies.

Geography is the only discipline that can pursue the study of environment in totality because:

(i) it studies the spatial attributes of all the phenomena including man in a given space and highlights complex man-environment relationships at different stages and phases in a time-space continuum while other sciences study individual phenomenon and do not bother for spatial organisation,

(ii) being an integrating science geography synthesises all the elements and components of planet earth into one body and links the social sciences with the natural sciences,

(iii) it lays stress on the 'synthesis of all near surface spheres into one interacting system' (Annuchin 1974). That is to say geography studies the biosphere (the interface of air, land and water) in totality (all components of biosphere-abiotic and biotic, their characteristics and interrelationships),

(iv) as regards the physical system it is geography that excels other sciences because geographers have the knowledge of structure, geomorphic processes, climate, vegetation and soils while other scientists specialise in only one of these aspects,

(v) geographers besides identifying complex relationships between man and physical environment have the capability of locating the distribution of such relationships in space, mapping them and exploring the causes of variations in distribution, and

(vi) 'geographers recognise that the quality of life layer varies from place to place in terms of richeness or poverty of life forms capable of being supported' (A.N. Strahler and A.H. Strahler, 1976). Geographers are the only scientists who can recognise and identify the environmental regions, locate them in space and present them on maps.

2.5 ENVIRONMENT (NATURE) AND WILDERNESS ETHICS

The dictionary meaning of nature is external world especially untouched by man. Thus, that part of the planet earth which has not been invaded by man becomes **'nature or wild area'** but the question arises, is there any such area on our earth which has not been approached by man? The answer is negative and thus we do not possess any space having virgin physical environment. Even Antarctica has been approached by several nations and once difficult equatorial rainforest in terms of accessibility has now been greatly invaded by man. So, the qualifying conditions for *'nature'* or *'wild area'* have to be lowered down and those areas should be termed **'nature'** or **'wild areas'** which have been least invaded by *'economic man'* or where the inroades of man's agricultural and urban impact have long been delayed (Strahler and Strahler, 1973, p. 393). When man appeared first on the earth the whole of the earth was *'wild area'* and the physical environment was in natural state but as the population grew and the skill of man increased, more and more *'natural areas' were converted into farms, villages, cities and towns, highways and several economic establishments and social institutions resulting into rapid rate of shrinking of 'natural or wild areas'*. The *'economic man'* equipped with superior technology continued and still continues to exploit the natural resources not withstanding the rebounding repercussions on his own existence. A group of concious people, now labelled as *'environmentalist'* has alarmed the economic man against the devastating impact of unplanned, unscientific and reckless exploitation of nature and has pleaded for to save a few of *'wild areas'* which are still least affected by man. The philosophy behind this movement (to quote, 'Chipko Movement by Bhat and Sunder Lal Bahuguna) is called wilderness ethic, 'Its supporters have run headlong into confict with those who have followed the frontier tradition, based on a deep-seated conviction that natural resources should be used and that natural landscape should be modified to provide farm land, timber and water supplies' (Strahler and Straherler, 1973, p. 3).

There is growing popular support for wilderness ethic for the last few decades. The concept of wilderness ethic has intrinsic scientific value because natural areas or wild areas least affected by human impact represent the ecosystem where the functioning of different components may be observed and studied properly and these may serve as base line for the comparison of such ecosystems which have been greatly impacted and modified by man with least impacted natural areas and thus the level of degradation can be fathomed and determined which may help in restoring the ecological balance of otherwise sick ecosystems. It may be pointed out that the *'materialistic man'* intoxicated by modern technology is reluctant to perceive the charm and value of natural areas in original state and thus such protected natural areas or wild areas termed as **'biosphere reserve or 'nature reserve'** may serve as an exhibition for the society to realise their significance. Almost every nation has attempted to protect a few wild areas as *'national park'*, *'wild life sanctuaries'* etc. but these have also been adversely affected by ever-increasing pressure of recreation industry.

Several attempts have also been made to preserve a few natural and wilderness areas as 'national parks', '*wild life sanctuaries*' etc. in India. '*The National Wild Life Action Plan* was started in 1983 with the basic purpose of formulation and implementation of strategies, programmes and projects for the conservation of wild life in future and increase in the protected area from the existing 3 percent to 4 percent of the geographical area of the country.

Wild Life Sanctuaries

The important Wild Life Sanctuaries are Bandipur Sanctuary (Karnataka), Bhadra Sanctuary (Chikmanglur, Karnataka), Bhimabhandh Sanctuary (Monger, Bihar), Bori Sancturary (Hosangabad, M.P.), Chandra Prabha Sanctuary (Varanasi, U.P. for Indian Lions), Dachigam Sanctuary (Jammu and Kashmir), Dalma Wild Sanctuary (Singhbhum, Jharkhand), Damp Wild Sanctuary (Aizwal, Mizoram), Dandeli Wild Life Sanctuary (Dharwar, Karnataka), Gandhi Sagar Wild Life Sanctuary (Mandsaur, M.P.), Warm Water Wild Life Sanctuary (Assam), Gautam Budha Wild Life Sanctuary (Gaya, Bihar), Hazribagh Wild Life Sanctuary (Hazaribhagh, Jharkhand), Wild Life Sanctuary (Kohima, Nagaland), Jaldapara Wild Life Sanctuary (Jalpaiguri, West Bengal), Wild Life Sanctuary (Adilabad, Andhra Pradesh), Kinnarasani Wild Life Sanctuary (Khamman, Andhra Pradesh), Manas Wild Life Sanctuary (Barpeta, Assam), Mudumalai Wild Life Sanctuary (Niligiri, Tamil Nadu), Someshwar Wild Life Sanctuary (South Kanara, Karnataka), Pachmarhi Wild Life Sanctuary (Hosanghabad, M.P.), Pakhal Wild Life Sanctuary (Warangal, Andhra Pradesh), Palamau Wild Life Sanctuary (Daltonganj, Jharkhand), Periyar Wild Life (game) Sanctuary (Kerala), Ranathambhaur Wild Life Sanctuary (Sawai Madhopur, Rajasthan), Sharavathi Valley Wild Life Sanctuary (Shimoga, Karnataka), Shikari Devi Wild Life Sanctuary (Mandi, Himachal Predesh), Simlipal Wild Life Sanctuary (Mayurbhanj, Orissa), Sonai Roopa Wild Life Sanctuary (Tejpur, Assam), Tansa Wild Life Sanctuary (Thane, Maharashtra), Tungbhadra Wild Life Sanctuary (Bellary, Karnataka) etc.

Bird Sanctuaries

Among bird sanctuaries important are Ghana Bird Sanctuary (Bharatpur, Rajasthan), Ranganthittoo Bird Sanctuary (Karnataka), Vedanthangal Bird Sanctuary (Chingleput, Tamil Nadu), Malapatti Bird Sanctuary (Nellore, Andhra Pradesh) etc. A national scheme known as '*Project Tiger*' has been launched to protect the tiger population in the country. The scheme '*project tiger*' ensures complete protection to the tiger species in a fiew speciallly selected tiger reserves (total 16) for scientific, economic, aesthetic, cultural and ecological purposes. These tiger reserves are at Manas (Assam), Palamau (Jharkhand), Similipal (Orissa), the Corbett National Park (Nainital, Uttarakhand) Melghat (Maharashtra), Bandipur (Karnataka), Sundarbans (West Bengal) and Cariska (Rajasthan).

National Parks

Besides, there are several National Parks in the country. These parks are fully protected to serve as museum of '*nature*' (some of the National Parks are also Wild Life Sanctuaries).

Important National Parks are Bandhavgarh National Park (M.P.), Bandipur National Park (Karnataka), Banarghatta National Park (Bangalore, Karnataka), Corbett National Park (Nainital, Uttarakhand), Dudhwa National Park (Lakhimpur Kheri, U.P.), Gir National Park (Junnagarh, Gujarat), Kanha Natioinal Park (Mandla, M.P.), Kazi Ranga National Park (Jorhat, Assam), National Park (Gangtok, Sikkim), National Park (Kurg, Karnataka), Pench National Park (Nagpur, Maharashtra), Rohala National Park (Kulu, Himachal Pradesh), Madhava National Park (Shivpuri, M.P.) Hazaribagh National Park (Hazaribhagh, Jharkhand) etc.

It may be pointed out that inspite of efforts taken by the central government in collaboration with the state governments to protect '*nature*' or '*wild areas*' the conditions of National Parks, Wild Life Sanctuaries and Reserve Forests are deteriorating day by day due to complex socio-politico-economic factors.

2.6 ENVIRONMENT AND RESOURCES

The natural resources, both abiotic and biotic constituting basic components of environment, in the form of matter and energy are of vital significance for the successful survival of all types of life on the planet earth in general and for human being in particular. In fact, all aspects of human society (social, cultural, political and economic) depend on resources. Therefore, the meaning, classification, assessment and evaluation, uses and abuses, conservation and management of all sorts of resources either natural or cultural, renewable or non-renewable, are very significant aspects of environmental geography. The very fundamental principle of resources is that resources, even renewable, are finite. For example, air and water are in abundance and are very much renewable but when they are polluted and degraded, they become unusable and non-renewable because it becomes very difficult to restore the original quality of air and water if they have been degraded beyond a certain critical limit.

The resources are fundamental base for the economic growth and development of human society but their withdrawal from the nature, mode of their uses by human being and their disposal have enormous adverse effect on the environment. It is, thus, imperative to study the linkages between resource use and the environment so that proper management of resources, both effective resources and resources out of place (waste materials after use) and remedial measures of environmental pollution and degradation arising out of resource use and disposal of waste materials may be made possible.

Resources are generally divided into (1) **natural resources**, and (2) **non-utilitarian resources.** Natural resources are those which belong to natural environment and include both (1) **abiotic natural resources** such as land, soils, air, water, minerals etc, and (2) **biotic natural resources** such as plants and animals. Biotic resources are also called **ecological resources** which are further divided into two broad groups e.g. (i) **natural** or **wildlife ecological resources** which include plant and animal resources of those natural ecosystems which have been least impacted by human activities, and (ii) **managed ecological resources**, which include plants and animals of those ecosystems which have been managed by man such as commercial and social forests, agriculture, and domestic animals.

Ecological resources are very important elements of the natural environment and ecosystems because their stability and survival largely depend upon ecological resources. Unwise and over-exploitation of ecological resources and destruction of natural habitats lead to environmental degradation and pollution and thus natural ecosystems become disturbed and destabilized. It is, therefore, necessary to pay more and more attention towards the preservation, conservation and management of ecological resources so as to maintain ecological balance and ecosystem equilibrium so that the survival of humanity may be assured.

Recently, more interests have been shown in the preservation and management of ecological resources because of their intrinsic value, aesthetic value, social benefits, scientific value, recreational and educational significance and overall environmental value because the stability of natural ecosystems depends upon ecological balance. D.R. Helliwell (1969) has shown that interests in the ecological resources are increasing world over because of various benefits of ecological balance e.g. (i) Direct returns (such as direct material and financial returns from hunting, shooting, fishing and food gathering), (ii) Genetic reserve (preservation of natural ecosystems and their ecological resources help in the breeding of new varieties of crop producing plants and animals), (iii) Ecological balance (maintenance and preservation of natural populations of plants and animals help in maintaining the ecological balance), (iv) Educational value (direct education of children about natural plants and animals and their biological functions), (v) Research value (natural ecosystems and ecological resources may serve as laboratories of research of biological functions and problems), (vi) Natural history interest (natural ecosystems may help in tracing the history of biological world), and (vii) Local value (ecological resources decide the characteristics of the place and area concerned).

The following aspects of natural resources are of vital concern to the present human society and future generations with respect to their exploitation and utilization :

1. the process of creation and regeneration of resources,
2. availability of resources (inequality in their spatial distribution),
3. exploitation and consumption of resources, and
4. adequacy and inadequacy of resources.

The processes of creation and accumulation of many natural resources, mainly mineral resources, are very slow and take millions of years for their formation and accumulation as vast mineral reserves such as the formation of fossil fuels (coal, mineral oil and natural gas) and metals. The availability of such resources for human use depends on accessibility of resources and rate of their exploitation. If the rate of exploitation of resources far exceeds the rate of their generation, the availability and supply of desired resources become poor. In case of some very important minerals such as mineral oil the availability may become almost zero as such minerals may be completely depleted.

While taking out the resources from the nature one should always bear in mind that resources are finite and have accumulated over a long geological period of time such as mineral oil, natural gas, coal and many key industrial minerals. These resources are being used at a very fast rate and there is every likelihood that we will run out of these resources within a few hundred years or even less. These resources are used for the supply of most of energy in the industrial, transport and domestic sectors. The combustion of mineral oils, natural gases and coal pollute the atmosphere. The very composition of the atmosphere in terms of natural gaseous composition is altered and modified which consequently affects the atmospheric processes. For example, emission of carbon dioxide through *'human volcanoes'* (chimneys of factories) increases the concentration of CO_2 in the atmosphere which in turn increases the green house effect of the atmosphere resulting into rise of temperature at the earth's surface and consequent changes in the radiation or heat balance of the earth. The use of petroleum in the operation of motor cars, trucks, rail engines and air crafts releases nitrogen oxides into the atmosphere which may deplete the ozone which is very vital for all types of life on the earth because depletion in ozone may allow ultraviolet solar rays to reach the earth's surface. This may result in the rise of temperature and thus alteration of terrestrial heat balance. The release of sulphur dioxide (SO_2) into the air by combustion of fossil fuels causes acid rains.

The most significant aspect of the environment in influencing human activity is the **availability of resources.** The richness or poorness, quality and quantity and above all the availability of renewable and non-renewable resources decide the type of human activities, economic viability, social organisations, political stability, international relations etc. Very rich reserve of mineral oil in the Middle East is the main reason for political instability in the Gulf Countries. The inter-state disputes of sharing river waters are because of location of rivers in more than one country. In fact, the level of economic development largely depends on natural resources.

The over exploitation and use of fossil fuels has posed a serious threat of climate change due to global warming caused by ozone depletion and increase in the concentration of greenhouse gases. It is estimated (IPCC report, 2001) that by the turn of the 21st century the concentration of atmospheric carbon dioxide would go upto 540-970 ppmv which may cause rise in temperature by 1.4 to 5.8^{0}C and sea level would rise from the present level by 9-88 cm. Due to excessive use of energy resources the international communities are scared of catastrophic adverse effects of future climatic changes on different spheres of man and nature e.g. deglaciation and sea level changes (rise), submergence of island nations and major coastal lowlands, atmospheric dynamics including evaporation and precipitation, increase in the frequency and magnitude and ferocity of tropical storms (e.g. hurricane Katerina and Wilma, which caused colossal destruction in 2005 in New Orleanse and Florida, USA, respectively), changes in global radiation balance, changes in the pattern of photosynthesis and ecological production, plant and animal communities, human health and wealth. The major sources of global environmental problems have been identified as changes in the atmospheric chemistry through air pollution due to rapid industrialization and urbanization by using huge amount of energy and other resources; population growth (increased demand of resources), advances in productive technologies, major land use changes mainly deforestation etc.

The reckless exploitation of natural resources and unplanned development without considering the basic principles of ecology and environmental science would cause without doubt, severe environmental and ecological problems which may threaten the existence of human society. It is, therefore, imperative to adhere to basic principles of environmental science and to pursue the path of sustainable environment, sustainable economy, sustainable development and sustainable society. We should also keep in mind the fact, while using natural resources, that the limit of these resources mainly non-renewable resources is finite, the mode of their formation is exceedingly slow process involving long geological period, the natural resources are public property and hence no one is entitled to misuse them, there should be, thus, rational exploitation and optimum utilization of resources. This means there should be proper management of resources based on ecological principles and the basics of ecological economics, sustainable environment, sustainable development and sustainable society.

Sustainability refers to ecological stability and continuity of overall human progress. The concept of **sustainable development** gained currency in 1987 in the report of the World Commission on Environment and Development (Our Common Future) wherein sustainable development was defined as 'meeting the needs of the present without compromising the ability of future generation to meet their own needs.' Development is a process of improving the life conditions of people through the exploitation and utilization of environmental (natural) resources in raw and manufactured state. The sustainable development aims at continuously improving the people's lives through rational exploitation and optimum utilization of natural resources on one hand and maintaining environmental quality and ecological balance on the other hand so that there may be continuous supply of natural resources to the present and future generations without harming the environment. It is evident that no doubt the environment provides all essential raw materials for development processes and hence it is also expected from the people to use the resources in such a way that these do not fall in short supply to future generation.

2.7 ENVIRONMENT, CULTURE AND SOCIETY

Environment and society are closely interrelated and are in fact interdependent. It is an established fact that different aspects of social organization and institutions could be developed on the basis of natural (environmental) resources. In fact, the environmental resources became the basis of **'built resources'** which we call cultural resources which represent different human social groups, social organization and social structures such as institutional, agricultural, industrial, economic, cultural, political, religious set-ups etc. Such social organizations and structures could be developed through different stages of development of human culture and civilizations primarily based on natural environment and its immense resources. The development of early civilization known as 'river valley civilization, such as Indus Valley Civilization, Nile Valley Civilization etc., could flourish along the major perennial rivers because these provided ample water, rich fertile soils for cultivation and wide flat flood plains for shelter. With the advancement in human skills and knowledge the role of man changed from a 'physical man' to 'social man', economic man' and ultimately to present 'technological man'. Consequently, man began to use natural resources more quickly and efficiently to build up modern social structures, which are no doubt detrimental to the environment.

If the natural environment helped in the evolution and development of different culture and civilizations from pre-historic period to the present day materialistic modern society characterized by ever-increasing consumerism and globalization, and different structures of the society such as highly mechanized agriculture, industrial establishments, commercial establishments, urban centers, educational, cultural and religious structures etc. on one hand, the existence and quality of environment now rest on the responses of human society and consequences of such social structures and cultural organizations to the environment on the other hand. Several issues like quality of environment, ecological imbalance, disruption of earth's natural ecosystems, environmental degradation and pollution, natural hazards and disasters, depletion of natural resources, sustainable development, sustainable society etc. have been raised since 1970s but any environmental problem can be approached and solved only after considering the society's response towards such problems in general and costs involved in setting the environmental problems right.

The responses or reactions of the society towards the consequences of 'environment improvement programme' can be determined on the basis of benefits acruing from such programmes and costs involved therein. For example, clearing of forest covers to meet the growing need of timber and agricultural land for everincreasing population leads to accelerated rate of soil erosion which causes siltation of river beds and consequent recurring floods. Is the society ready to stop massfelling of trees to check soil erosion and floods. Is the society ready not to expand the farmland and allow the teeming millions to die due to hunger and starvation? The modern industries and evergrowing urban centers are responsible for air and water pollution beyond repair. Is the modern society ready to restrict the industrial and urban growth? Is the society ready to expend money, which is meant for development programmes, on environment programmes such as halting deforestation and starting reforestation and afforestation, checking soil erosion and river flood, halting the pace of industrialization and urbanization, management of environmental degradation and pollution and so on? Many more questions may be raised in terms of relative value of resources to be spent on the programmes of the restoration of the quality of environment and pollution abatement programmes and immediate material gains to the society accruing from such programmes. All these depend on interests and desire of the society in improving and maintaining the quality of environment.

Without doubt the society is now awakened towards environmental problems and the public concern about the quality of environment has reached the emotional peak but can this tempo be sustained for long time? Can this be translated into practice? The environmental improvement measures being costly and long-term investment of time, money and resources may eclipse the tempo, jeopardise the public interest and taboo the implementation of environmental improvement programmes.

Issue attention cycle : According to A. Downs (1972) public interest in environment changes through time and the whole sequence of changes is completed in five stages termed as *'Issue Attention Cycle'*. (i) **First Stage** or pre-problem stage is characterised by no public attention towards environmental problems except a few experts and interest groups who are seized with such problems, (ii) **Second Stage** : Stage of alarmed discovery and euphoric enthusiasm-when the issue of environmental problems catches the public attention and the public are so alarmed and become so enthusiastic that they readily respond to solve the problems without having any care for the cost of investment, (iii) **Third Stage** is marked by realisation of the cost of significant progress. That is to say that the public become aware of the cost of investment. It is also realised that the technological development may not always be the best solution to the environmental problems, (iv) **Stage Four** is characterised by gradual decline in public interest towards environmental improvement programmes due to realisation of higher cost of solution of environmental problems and difficulty in implementing the environmental improvement programes, and (v) **Post Problem Stage** is marked by lessening of public interest in the issues of environmental concerns but the public interest occasionally surges and again keeps a low ebb, thus the public interests in environmental problems occur in spasmodic manner.

The interaction between environment and society depends largely on the social and political systems within which arise the environmental and ecological problems. The capitalistic and socialistic systems perception and reactions to the environment are quite different. Even the ecological situation varies from one country to the other and one region to the other because of uneven distribution of natural resources, uneven economic and social development, dissimilarity of demographic factors, varying view points of the government and individuals towards environment etc. The capitalistic system of government of the west is full of contradictions regarding the exploitation of natural resources, rate of development, use of modern technologies and conservation of environmental resources and maintenance of ecological balance. Continuous but exceedingly increasing rate of rapacious exploitation of natural resources and uncontrolled development by the developed western world, monopolistic groups and selfish international companies, are responsible for alarming situation of grave environmental crises and ecological imbalance not confined to the limits of their own countries and regions but to the whole globe. The inherent ideology of capitalism is to increase production with minimum production cost but for maximum profit leading to accumulation and hoarding on the one hand and to shift the responsibility of environmental crises to developing and underdeveloped countries on the other hand. Conversely, they are raising the siren of 'ecological catastrophe' and are propagating the idea of 'limits to growth', 'society of zero growth', 'equilibrium society' etc. so that consumption of natural resources may be frozen and economic growth suspended. No doubt, there are individual groups and even the general public in the west which are sore over the misuse of modern technologies and deterioration of environment but the 'capitalist ideologists, politicians and the government are suppressing or subordinating the mass movement for the defence of environment to their own ends and to gloss over and blur the close connection between the ecological crisis and the set of contradictions typical of modern capitalist society, to divert the masses of working people (especially the youth) from their class interests, and to convert the movement into a purely 'conservation' one' (P.N. Fedoseev, 1983). For example, there is mass movement in the U.S. public against the nuclear prolification and possible nuclear disaster and holocaust but the U.S. Govt. is going ahead with its nuclear programmes. In fact, the pessimistic ideology of the western world about environmental degradation is painting a gloomy picture of ecological problem before the developing and underdeveloped world, so much so to discourage the use of modern technology and launching of developmental programmes so that they may remain perennial markets where the factory produce from western world may continue to be dumped. It may be pointed out that intensive researches in the field of nonpolluting and ecologically safe technologies are being conducted and polices of conservation of nature are being pursued through appropriate legislations even in the western world but these are blocked by vested interests of monopolistic groups.

The socialistic system of government mainly of the Communist Block lays more emphasis on the social importance of natural resources and environmental and ecological problems and on the urgent need to tackle these problems. 'Fundamental traditions of investigating ecological problems have matured in Marxism, which disclosed the dialectic of the interaction of society and nature in demonstrating the sources of the unity and opposition of man and his habitat' (P.N. Fedoseev, 1983). Marxism preaches to organise society's control over the rapacious exploitation of natural resources and to develop harmony between man and nature.

The inherent socialist ideology of public ownership of natural resources is explicit expression of effective nature conservancy. In other words, the deep involvement of society in production and consumption processes injects a sense of belonging to natural wealth and therefore the public becomes conscious about the uses and misuses of natural resources and possible danger emanating therefrom. The socialist ideology proclaims to have socio-ethical interpretation and evaluation of present-day ecological problems of **'man society-nature-system'** and to lay emphasis on socio-ecological research to find out ways and means for developing new pollution-safe technologies aiming at careful and economical use of natural resources, transforming productive forces and human activity in terms of current ecological situation. According to I.T. Frolove (1983) the essence of ecological policy pursued in the former U.S.S.R. (Now Russia) is to reduce the unfavourable consequences of scientific and technical progress to the minimum on the ecological plane and to increase its positive effects on the natural environment to the maximum'.

It may be summarized that the health of both environment and society depends on symbiotic relationship between society and environment so that the goal of 'sustainable environment and development', and 'sustainable society' may be achieved. The United Nations Organization through its publication entitled 'Caring for the Earth : A study for Sustainable Life' (1991) has set out the following principles for sustainable society :

- Respect and care for the community of life; co-existence and harmonious community life by respecting each other,
- Improvement of quality of human life involving improvement in health, education, access to the resources which are essential for decent standard of living, political freedom, guaranteed human rights, and freedom from violence,
- Conserve the earth's vitality and biodiversity : conservation of life-support systems (eco-

logical processes), biodiversity (all species of plants, animals, micro-organisms, genetic stocks within each species, and different types of ecosystems), ensure that uses of renewable resources are sustainable,

- Minimise the depletion of non-renewable resources,
- Maintain the earth's carrying capacity,
- Change personal attitude and practices towards the exploitation and utilization of natural resources and environment,
- Enable communities to care for their own environment (community participation in the management of natural resources and maintenance of environmental quality),
- Provide national framework for integrating development and conservation (of natural resources), and
- Create global alliance for globally shared resources, especially the atmosphere, oceans and shared ecosystems.

Reproduced from 'Caring for the Earth' (1991),
an IUCN, UNEP and WWF (of UNO) publication

3

MAN-ENVIRONMENT RELATIONSHIPS

3.1 APPROACHES TO THE STUDY

The study of relationships between man and environment has always been, in one way or the other, a focal theme in geography but the concept of geography as environmental science and facets of man-environment relationship changed through time with the development of human society and the dimension of environment. In the beginning of the process of evolution of man and his society physical elements of the planet earth e.g. terrain, soil, water, climate, flora and fauna formed man's environment and man was basically a **'physical man'** because of his limited wants, requirements and total dependence on nature. As the man became social, economic and technological man, he broadened his environment by creating his own environment (built environment) through his design and skill to have provision for better food, shelter, access and comfort. The man-environment relationships, thus, can be perceived and evaluated in a variety of ways and approaches.

1. Environmental Deterministic Approach

This approach is based on the basic tenet of **'earth made man'** and pays more attention on the complete control of physical environment on man and his activities. In fact, according to deterministic perspectives of man-environment relationships, man is subordinate to natural environment as all aspects of human life viz. physical (health and comfort), social, economic, political, ethical and aesthetic etc. not only depend but are dominantly controlled by physical environment. Though this deterministic or environmentalistic approach blossomed in the writings of E.C. Semple (1910) in the second decade of the 20th century but its seeds were already sown in the second half of the nineteenth century. In fact, the publication of 'The Origin of Species' of Charles Darwin in 1859 laid the foundation stone of the concept of environmental influences on man and other organisms.

Fredrich Leplay demonstrated the effects of physical environment on society through his dictom, **place (environment)-work-folk**, which shows that environment (place) conditions the type of work, and work shapes, atleast in part, the social organisation (folk) (George Tantham). The concept was further elaborated with the tone of firm determinism by Demolins (1901 and 1903). He postulated that 'society is fashioned by environment'. He attempted to analyse social structure in terms of 'geographical environment'. Three American geographers e.g.

W.M. Davis, E.C. Semple and E. Huntington strengthened the concept of environmentalism. W.M. Davis, though more known as a geomorphologist, attempted to link nature with man. His two essays published in 1903 and 1906 clearly demonstrate that human activities, racial characteristics and cultural elements are related to greater extent to the environment. He classified human elements in terms of physical elements and pleaded for the control of physical elements over human elements but later on he modified his earlier concept of man-environment interrelationships as the main subject matter of geography and treated description of regions of the earth as the core of geography.

The concept of environmentalism culminated in 1910 when American geographer E.C. Semple published her book 'Influences of Geographic Environment' wherein she opined that 'man is the product of the earth's surface. This means not merely that he is a child of the earth, dust of her dust, but the earth has mothered him, fed him, set him tasks, directed his thoughts, confronted him with difficulties that have strengthened his body and sharpened his wits, given him his problems of irrigation and navigation and at the same time whispered hints for their solutions' (E.C. Semple, 1910, pp.1-2). Deterministic/environmentalistic approach was fully organised on scientific plane by E. Huntington. His 'Civilisation and Climate' (1915), 'The Human and Habitat' (1927), ' Season of Birth' (1938) etc. clearly demonstrate the influences of physical environment on man. His postulation that 'climate not only influences human life but also his birth' proves that he was a strong advocate of environmentalism.

It is apparent that the deterministic/environmentalistic school advocating control of nature on man dominated the geographic thoughts upto 1920. According to Grossman (1977) the first two decades of the twentieth century was influenced by three aspects of contemporary scientific thoughts. (i) Darwinian concepts of natural selection, adaptation and survival of the fittest. Darwin's argument that 'gradual modification and diversification of organisms stems from a process of natural selection and adaptation to environmental factor both being slow but ongoing over long period of time' (C.C. Park, 1980, p. 113) is fully reflected in 'Ratzels' social Darwinist concept of geography as the study of man's relationship to his environment' which 'had held sway-whether it was with emphasis on the role of human choice (as in the possibilist tradition of French geography) or on influences and controls exerted by nature on the course of development of human societies (as visible, for example, in the works on Ellen Churchil Semple in U.S.A. and A.J. Herbertson in U.K.) (R.D. Dikshit, 1985, p. 69). (ii) Application of deductive approaches to scientific enquiry, and (iii) Acceptance and application of Newtonian concept of cause-effect relationships.

2. Teleological Approach

Teleological approach is based on religious faith of man being superior to nature and all other creatures. This school emanated from the teachings of Judeo-Christian religious tradition which preached that 'man is superior to all creatures and every thing is created for his use and enjoyment'. This ideology of man-environment/nature relationship fostered the man to exploit natural resources and to subdue nature without considering the after-effects of reckless and uncontrolled plundering of natural resources. This approach of man-environment relationship led to excessive and rapid rate of exploitation of natural resources in North America and Western Europe as well as in other parts of the world which were their colonies. A host of scientists and environmentalists have held this religious tradition responsible for present-day ecological crises.

This approach of thinking of man towards nature and environment stimulated Europeans to spread out all over the world in search of unexplored land and resources. Consequently numerous colonies were established in all of the inhabited continents. After 1750 there began a race for rapacious exploitation of natural resources and widespread industrialization in Europe and America. The process continued for the last three centuries and created most of the present-day environmental problems.

3. Possibilistic Approach

Possibilistic approach to the study of man-environment relationships emerged through the criticism of environmental determinism and overtone of teleological approach. Right from the very inception of the school of environmental determinism there was dissenting voice raised by those who believed that 'no doubt physical environment influences man and his activities but there is ample scope for man to change the environment so much so that it becomes suitable for man and his society'. The German philosopher Hegal, fed. up with physical determinism remarked, 'Don't talk to me about environmental determinism. Where the Greeks once lived, the Turks live now, that settles the matter.' While reviewing man-environment relationships, Kirchoff concluded that 'man is not an automation without a will of his own. The suggestions thrown out by the nature of his birth place some times find him a docile, some times a different people'. A group of people did not approve the principles of environmental determinism. Though they did not discord the barriers of environment but they gave due weightage to active man. They believed in the capacity of man to modify and mould the nature in their own ways. This concept of possibilism was founded by Febvre who has remarked, 'man is a geographic agent and not the least. He every where contributes his share towards investing the physiognomy of the earth with those 'changing expressions' which are the special charge of geography to study'.

Two French geographers, Vidal de la Blache and Jeans Bruhnes and American geographers Isiah Bowman and Carl Sauer founded the school of possibilism which is based on the philosophy of possiblism in nature at every stage in a given space and time as remarked by Febvre, 'There are no necessities, but every where possibilities and man as a master of these possibilities is the judge of their use'. Possibilists were quite aware of the limitations of freedom of man to dictate terms to 'nature' and thus they did believe that man cannot fully tame the nature and is not always victorious. Febvre, a staunch believer and advocate of possibilism has accepted that 'Man can never entirely rid themselves, whatever they do, of the hold their environment has on them. Taking this into consideration they utilize their geographical circumstances more or less according to what they are and take advantage of their geographical possibilities. But here as elsewhere there is no question of necessity'. Jeans Brunhes also accepted the limitations of man's control over nature as is evident from his writings, "The power and means which man has at his disposal are limited and he meets the nature bounds which he cannot cross. Human activity can within certain limits vary its play and its environment, but it cannot do away with its environment, but it can often modify it but it can never suppress it and will always be conditioned' (Jeans Bruhnes).

Possibilists replaced more deterministic terms **'control'** by **'influence'** and **'influence'** by more moderate terms **'response'** or **'adjustment'**. G. Tantham while bridging the gap between environmental determinism and possibilism maintained that 'the maxim should not be conquest of nor submission to, but cooperation with nature'. *Harlan Barrows* (1923) presented an alternative approach and defined geography as **'human ecology'** wherein he pleaded for the study of mutual interaction between man and environment, the study of human societies in relation to their environment and environmental adaptation in place of environmental control.

4. Economic Deterministic Approach

This approach is based on the basic ideology of man's mastery over environment and continued economic and industrial expansion through the application of modern technologies. "The basic thesis of the growth (affluence) school is that because economic growth is required for political, social and economic stability, the 'quality of environment' normally assumes lower priority in formulating planning proposals and in long-term planning because the deterioration of the environment is generally protracted and socially less oblique than a deterioration in the economy' (C.C. Park, 1980). In fact, 'economic determinism' based on two fallacious assumptions of (i) positive correlation between the population of a given region and the level of economic development and activity in that region, and (ii) the interactions of people, resources and society being governed by universal economic principles as observed by W.Zelinsky (1966), believes in man's ability to solve environmental problems arising out of continued economic growth and industrial expansion. It may be pointed out that this extreme concept of economic determinism led to rapacious exploitation of natural resources in the western developed countries and thus created most of the environmental and ecological problems of global dimension.

The everincreasing environmental problems, mainly environmental degradation and pollution, the alarming problems of ozone depletion and global warming, consequent upon excessive use of natural resources in the last century softened the attitudes of economists towards nature and environment which is validated from the emergence of the concepts of **'environmental economics'**, **'ecological economics'**, **'steady-state economy'** etc. Ecological economics means 'application of ecological insights to economic analysis, incorporating ecological principles and priorities into economic accounting system' (W.P., and M.A. Cunnighan, 2003). It is now believed by the economists that for sustainable development and steady-state economy the maintenance of environmental quality and ecological balance is a prerequisite condition.

5. Ecological Approach

Ecological approach to the study of man-environment relationships is based on the basic principle of ecology which is the study of mutual interactions between organisms and physical environment on the one hand and interactions among the organisms on the other hand in a given ecosystem. Thus, man is considered as an integral part of nature/environment. 'The relationship of man with the natural environment should be symbiotic and not exploitative nor suppressive' (C.C. Park, 1980). This school recognises man, being most skilled and intelligent, as the leader of all biota and steward of the earth. This approach further lays emphasis on wise and restrained use of natural resources, application of appropriate environmental management programmes, policies and strategies keeping in view the ecological principles so that already depleted natural resources are replenished (wherever possible), degraded environment is set right and ecological balance is maintained.

The ecological approach lays emphasis on rational exploitation of resources and optimum utilization through recycling of resources. The following facts should be taken into account while using natural resources :

- that the environment is a closed system,
- that the natural resources are finite,
- that the geological processes of the formation of abiotic resources, such as metals and mineral oil, are exceedingly slow and take millions and billions of years for their formation and accumulation.
- that the natural resources are free gifts of nature which should be used judiciously,
- that the natural resources are public property and hence no country or agency is allowed to misuse them,
- that the environmental/natural system (ecosystem) is governed by in built self regulatory system (homeostatis) which states that any change in any component of the environment effected by natural factors is suitably counterbalanced by changes in other components but if the changes brought in by human activities are so enormous that these exceed the resilience of homeostatic mechanism of the natural system, serious environmental problems emerge, which become lethal to all biota in general and humans in particular,
- that the political and economic stability depends on ecological and environmental stability,
- that the sustainable society and sustainable development may be possible only when the environment also becomes sustainable,
- that the extraction of mineral resources and their processing leave immense quantity of wastes which degrade the environment,
- that the sustainable development, aiming at real upgrading of quality of life of the people and improving human welfare for long-term within the limit of the resources of the planet earth, can be achieved without compromising with the ability of the nature to provide sustainable yield to the future generations and without degrading the environment etc.

It may be pointed out following C.C. Park (1980) that the debate on man-environment relationships should be viewed taking into account the multi-dimensional aspects of environmental problems which are the result of complex series of several factors viz. physical, economic, social, political, ethical etc. but any positive approach adopted for the study of man-environment relationships must take into account the fact that there should be harmony and not hostility between man and environment. It is obvious that the relationship between man and environment is two-directional as the environment affects and influences man and in turn man also influences and modifies the environment. This type of mutual interactions and relationship between man and environment is symbiotic in character.

Man-Environment Interactions

Thus, the interactions between man and environment may be systematically studied on the basis of bi-dimensional aspects of man-environment relationships as follows :

1. Environment and man i.e. environmental controls on human health and activities, and

2. Man and environment i.e. adverse effects of human activities on environmental system vis-a-vis environmental quality and ecological balance.

3.2 ENVIRONMENT AND MAN

The environment affects man through (i) biophysical limitations, (ii) behavioural controls, and (iii) resource availability.

1. Biophysical Limitations

Weather and climate affect human well-being and health. The study of reactions of human body to changes in the atmospheric environment is known as **'human biometeorology'** which lays emphasis on to 'establish how much of the overall biological variability is the result of changes in weather, climate and season' (J.E. Hobbs, 1980, p. 60). According to M. Bates (1966) three levels of climatic environment affect human behaviour viz. (i) **'microclimate'** (which represents weather conditions surrounding an individual organism), (ii) **'ecological climate'** or **'ecolimate'** (represents weather elements of the habitat of the organisms, in the case of man the habitat may be his house and working places like factory, office, mine, agricultural farms, pasture or forest), and (iii) **'geographical climate'** or **'geoclimate'** (weather conditions of larger areal unit and longer temporal span).

Biologically, human body can function properly only in certain suites of environmental conditions in terms of oxygen, heat, light, humidity and precipitation, wind, lightning, fog, clouds, atmospheric electricity and space. Even the surviaval of human body depends on the above factors. Lack of required amount of oxygen at higher altitudes makes human survival impossible. Excessive heat and humidity retard body and mental growth whereas very high or very low temperature on the one hand adversely affects human body and on the other hand makes food a scarce commodity to support human life. **Micro-climate** affects leisure, recreation, comfort etc.

Certain non-infectious diseases and medical disorders have been correlated with environmental factors such as geochemistry of rocks, soils and water. Concentration of a few trace minerals in the rocks, soils and water in the Uttarakhand Himalaya causes stomach disorders through diarrhoea, dysentery etc. M. Cole (1971) has shown correlation between certain forms of cancer and cardio-vascular troubles and geochemical properties of soils and water whereas B.E. Davies and R.J.F. H. Pincent's (1975) study of *'minerals and morbidity'* has revealed relationships between stomach cancer and hardening of tissues and arteries of human body (sclerosis) and certain trace minerals in the soils and water.

Certain diseases and illnesses have been related to atmospheric conditions. E.H. Derrick (1965, 1966, 1969) has related seasonal, annual and short-term variations in asthma in Brisbane (Australia) to variations in weather conditions. He has related weeks with high incidence of asthma with decrease in mean and minimum temperature, dew point, relative humidity and rainfall but increase in sunshine hours whereas low incidence of asthma has been found in those weeks which are characterised by higher dew points and relative humidity, more rainy days, low temperature ranges and fewer hours of sunshine. Many more investigators have established evidences to demonstrate close association between asthma and cold e.g. L. Greenburg, F. Field, J.I. Reed and C.L. Erchardt (1964 and 1967, relationship between asthma and temperature change in New York), S.W. Tromp and J. Bouma (1965, increase in asthma among 16 years old children during periods of cooling in the eastern Netherlands), M.J. Spondnik et al. (1996), concluded that airflow resistance of 100 students of Baltimore, U.S.A., increased with decrease in temperature etc.

J.B. Hanesen and S.A. Pedersen's (1972) study of relation between barometric pessure and certain ailments has demonstrated that there is positive correlation between rapid changes in the atmospheric pressure and the incidence of perforated duodenal ulcers and peripheral arterial embolism. F.K. Davis has found close relationship between temperature changes and frequency of haemorrhaging from duodenal ulcers. A few researches have revealed seasonal occurrences of many diseases and ailments e.g. scarlet fever, diphtheria, and jaundice are more prevalent during winter whereas measles, influenza and chicken pox are most common in spring in Switzerland (J.E. Hobbs, 1980).

2. Behavioural Controlls

Various combinations of environmental factors have not only affected but conditioned racial characteristics in different parts of the earth's surface. Environment also influences and conditions thoughts, ideologies and culture of human being. Even the social, economic and political behaviour is influenced to certain extent by man's perception of environmental factor and his responses to these factors. Frequency and magnitude of extreme natural events and environmental factors like vulcanicity, earthquakes, floods, droughts, landslides, atmospheric storms etc. influence man's perception of natural environment and decide his reactions and responses to these events. For example, the inhabitants of riparian tracts of major alluvial rivers of the Ganga plain of North India are largely adversely affected by recurrent floods and riparian decay and thus they conceive that rivers are sources of perpetual disasters but the inhabitants of equatorial rainforest living in the riverine tracts are seldom aware of floods and disastrous role of rivers. The ravinous tracts of the Chambal valley (India) have not only moulded the social behaviour of the local people but also of the people of the adjoining areas as the circuitous network of ravines provides ideal hideouts and the people after committing crime easily escape to these ravines which extend standing invitation to criminals by providing safe shelter though with least comfort. Many more examples may be cited to demonstrate the impact of environment on human behaviour, his perception and responses to environmental factors.

The 1991 super cyclone of Orissa, the 2001 Bhuj earthquake in Gujarat (India), the 2004 tsunami onslought in Thailand, Sumatra, Sri Lanka and the eastern coasts of India, the 2005 Mumbai furious floods etc. created panic and fear among thousands of family which suffered from mental disease due to death of their kith and kins, separation of family members, destruction of property and dwellings.

3. Resource Availability

The most significant aspect of the environment in influencing human activity is the availability of resources. The richness or poorness, quality and quantity and above all the availability of renewable and non-renewable resources decide the type of human activities, economic viability, social organisations, political stability, international relations etc. Very rich reserve of mineral oil in the Middle East is the main reason for political instability in the Gulf Countries. The inter-state disputes sharing river waters are because of location of rivers in more than one country. In fact, the level of economic development largely depends on natural resources.

3.3 MAN'S INTERACTIONS WITH THE ENVIRONMENT

HISTORICAL PERSPECTIVE

Man is an important part of the biotic component of the environment and simultaneously he is also an important factor of the environment. Thus man plays important roles in the natural environmental system in different capacities such as 'biological or **'physical man'**, **'social man'**, **'economic man'** and **'technological man'**. All the natural functions of human beings such as in birth, growth, health and deaths are affected and determined by the natural environment in the same manner as in the cases of other organisms but man being most developed and advanced animal, both physically and mentally and hence technologically, is capable of making substantial changes in natural environment so as to make it suitable for his own living. The role of most primitive biological or 'physical man' in the functions of natural environmental system was fundamentally that of user of environmental resources and thus he played the role of a factor of the environment but as the skill and technology of man developed with cultural development his roles towards natural environment also changed progressively such as from user through modifier and changer to destroyer of the environment.

So, it is the technology of man which has drastically changed the man-environment relationship from prehistoric period to the present most advanced industrial period. In fact, 'the industrial and scientific revolutions have led to rapid changes in our environment, but all technology, from the most primitive to the most advanced, causes some changes in the environment' (D.B. Botkin and E.A. Keller, 1982). It may also be stressed that religious ideas and materialistic outlook of man have also played significant roles in changing man-environment relationships on a large-scale. Modern technological man, intoxicated by highly advanced technology and materialistic viewpoints, has changed and is changing the environment for his vested interests to such an extent that even the very existence of human beings is threatened.

Thus if we look at historical progression of man-environment relationships it becomes clear that purely natural relationship between 'physical primitive man' and natural environment during prehistoric period has changed to hostile relationship between *'technological man'* and the environment at present. This substantial change and shift in the nature and magnitude of man's interactions with the natural environment has given birth to numerous environmental problems of serious consequences because the changes effected by man in the environment have become unadjustable by the inbuilt selfregulatory mechanism of the natural environmental system/ecosystem. The study of changing relationships between man and environment in historical perspective may help in demonstrating the increasing adverse impacts of human activities on the environment. The changing relationships of man with the natural environment from prehistoric to modern periods may be divided into four stages as given below :

1. Period of hunting and food gathering
2. Period of animal domestication and pastoralism
3. Period of plant domestication and agriculture
4. Period of science, technology and industrialization.

1. Period of hunting and food gathering

This period is related to most primitive man when he was basically a part of natural environment and his function was like other animals. Thus the primitive man was functionally a **'biological man'** or **'physical man'** because his basic requirements were limited to food only which he could collect from his surroundings. Thus the primitive man used to satisfy his hunger by fruits which were easily obtained from plants and trees and he spent his nights in the caves or on the trees. The relationship between man and the environment was very friendly, cordial and sweet. The natural environment provided all requirements of early man (food and shelter) and thus man was totally dependent on his environment. Though even early man used to derive resources from the nature (only food) but this did not make any change in the natural environment because only fruits were used.

With the march of time man learned to hunt animals for his food. This led to first attempted intentional step of man in the exploitation of natural resources. Even the hunting of animals (significant component of biotic components of natural environment) by early man did not make any change in the natural environmental system because of his limited requirement and very low population and unorganized society.

The **discovery of fire** made a significant change in the attitude of man because now he learned to cook animal flesh before eating. This practice required wood which he used to derive easily from the forest. The demand of wood for burning purposes to roast animals made another significant starting point in the technology as the man had to invent some divice to cut and chop trees and their branches to get firewood. He also invented some tools to kill animals. Thus the **discovery of fire and invention of tools and weapons** made the man capable of exploiting natural resources from the forest through fruit gathering and animal hunting.

The first destruction of environment started with inadvertent **burning of forests** due to carelessness of man while cooking and roasting the animals with fire. This led to a chain of effects by man on his environment. He might have seen animals running away due to inadvertent man-induced fire. He, thus, might have intentionally used fire to drive away dangerous animals from his surroundings. At a much latter date he also might have used fire to clear the forest for different purposes (such as creation of habitats, farmland etc.). Since the early man depended exclusively on fruit gathering and animal hunting to satisfy his hunger, he was very much mobile because he had always to move in search of food. This mobile tendency of early man was also responsible for least interference with the environment in terms of its destruction.

It may be concluded that "fire was one of the first major technological tools used by human beings to change the environment for their own benefit. In deed, fire has been used around the world by early people to clear the land for improved travel and hunting or for farming" (D.B. Botkin and E.A. Keller, 1982).

2. Period of animal domestication and pastoralism

With the march of time early man learned to domesticate animals for his own benefits. He might have domesticated some milch cattle and some animals for meat in the beginning. Slowly and slowly his herd of domesticated animals might have substantially increased. This trend might have necessitated to create habitats (ranches fenced with branhes of trees and thorny bushes) though for temporary stay for the domesticated animals. Thus early man used to burn forest to create temporary home for the domesticated animals, to exploit forest resources to gather fodder for his animals and food for himself. Domestication of animals might have also given birth to group or community life among the early people in order to protect their animals and themselves from wild animals.

With the march of time the early people might have gathered larger herds of domesticated animals. They still stuck to nomadic way of life as they had to move from one place to another place in search of water and fodder for their animals and food for themselves. Thus increase in the population of domesticated animals also led to increase in the population of early people which ultimately led to meaningful exploitation of environmental resources but this could not change the natural state of the environment because the population of early people and their domesticated animals was still under manageable size and the changes brought in by human activities in the environment were well within the limit of self-regulatory mechanism of the natural environmental system/ecosystem.

D.B. Botkin and E.A. Keller (1982) have maintained that prehistoric people changed the environment (i) by hunting (of animals for his food); (ii) by decreasing the abundance of some animals through hunting; (iii) by increasing the abundance of others when they altered the habitats (of animals) and made them more favourable to those species; (iv) by burning (of the forests for making his and his domesticated animal's movement easy, for creating homes for his animals etc.); (v) by domesticating plants and animals; (vi) by changing erosion rates by agricultural and other land clearing practices and thus altering soils as well as vegetation, and (vii) by transporting organisms into new areas from which they had been isolated by geographical boundaries.

3. Period of plant domestication and agriculture

Domestication of plants for food was hallmark in the development of human skill of taming and controlling the biotic component of the natural environmental system or ecosystem. Domestication of plants initiated primitive type of agriculture and sedentary settled life of people who previously were nomads and wanderers. But still many of the people used to live nomadic life. It may be pointed out that initiation of cultivation of mainly food crops resulted into the formation of social groups and organizations which gave birth to early human civilization known as **'river valley civilization'** because most of people settled in the river valleys due to availability of water and fertile land for cultivation.

Thus the emergence of socially organized human communities, human civilization and farming practices changed the existing almost friendly and cordial relationships between man and his natural environment. Gradual but continuous improvement in farming practices resulted into gradual increase in human population and in the number of domesticated animals and thus more and more virgin forest lands were cleared through felling of trees with the help of more advanced tools and weapons and through burning of forest in order to increase the agricultural land so that increasing number of human beings could get food. People also moved from the area of greater concentration (of people) to other areas in search of new fertile land. This led to spread of human population and thus destruction of natural ecosystem. **Shifting or jhuming cultivation**, which was most prevalent form of primitive cultivation, was responsible for more destruction of natural forsest. Such farming practice is still in operation in many of the hilly regions of south and south-east Asia. North eastern hill states of India are still characterized by jhuming cultivation.

With the march of time man developed his own environment known as **'the cultural environment'** by building houses and thus creating villages and towns and cities, by developing social institutions like schools and colleges, by building places of worships like temples, churches, mosques etc., by constructing roads, railroads, bridges, canals etc. It may be pointed out that all these and many more elements of 'cultural environment' were evolved through various stages of agricultural development upto 1750 or say before industrial revolution. All these could be possible because of development in technologies which changed the physical and social man into **'economic man'** which led to the **phase of industrialization** but in the beginning no serious damage was done to the natural environment though significant changes, no doubt, were brought in the environment. Though man became successful in transforming the natural environmental resources in his way but the nature was still supreme and master and man continued to be guided by physical environment.

4. Period of science, technology and industrialization

The dawn of industrial revolution in late nineteenth century (say precisely since 1860 A.D.) with the emergence of science and development of more efficient and sophisticated technology initiated the hostile relationship between man and his natural environment. Extreme teleological and economic deterministic concepts of the western world, advanced technologies and scientific techniques of the modern **'technological man'** led to reckless and indiscriminate rapacious exploitation of natural resources for industrial expansion and urban growth which have altogether created most of the present day environmental and ecological problems of global dimension.

The impacts of modern technological man on natural environment are varied and highly complex as the transformation or modification of one natural condition and process leads to a series of changes in the biotic and abiotic components of the biospheric ecosystems.

The man's impact on environment fall into two broad categories as follows :

(i) Direct or intentional impacts, and

(ii)Indirect or uninternational impacts.

(1) Direct Impacts : Direct or intentional impacts are preplanned and premeditated because man is aware of the consequences, both positive and negative of any programme which is launched to change or modify the natural environment for ecnomic development of the region concerned. Such changes include land use changes (clearing of forests and burning of grasslands for crop cultivation; felling of trees for commercial purposes; changes in cropping patterns in relation to new farming techniques, new high yielding seeds, irrigational facilities etc.), constructions and excavations (constructions of dams, reservoirs and canals, diversion and manipulation of river channels, construction of embankments and dykes to protect the area from floods, construction of roads and bridges, increase in urbanisation, mining, drilling of mineral oils, withdrawal of groundwater etc.), agricultural practices (mechanisation of agriculture, use of chemical fertilisers, pesticides and insectisides), weather modification programmes (cloud seeding to induce precipitation, dispersal and clearing of clouds and fogs, checking of hailstorms etc.), nuclear programmes etc.

It is significant to point out that the effects of such anthropogenic changes in the natural environment are noticeable within short period and may continue to affect the environment for long time but these effects are reversible because both before and after studies (which are possible) may enable the man to set the adverse effects right to certain extent if so intended by making suitable changes in the initial programmes. For example, deforestation (either for cropland or for commercial purposes) leads to accelerated rate of soil erosion resulting into gully erosion and loss of soil fertility on the one hand and enormous increase in sediment load in the river which causes severe floods on the other hand. These chain effects can be effectively stopped by reforestation of the deforested areas. Similarly, changes in farm practices, which introduce adverse changes in the environment, may be rechanged to suit the environmental and ecological situations.

As regards **weather modification and transformation of climate at local and regional levels** through purposive human action, the after-effects are seldom pre-meditated. It is important to note that it is not possible to master meteorological processes because 'there is no permanent channels of control in the atmosphere such as in machines and living organisms' (E.K. Fedorov, 1983, p. 93) but man can control or divert undesriable natural atmospheric processes and disturbances such as cyclones, hailstorms, precipitation, clouds etc. One of the intentional or purposive actions of man to modify meteorological phenomena is **'cloud seeding'** to stimulate clouds and precipitation through crystallisation of supercooled drops through the application of solid carbon dioxide and certain compounds of iodine. 'A few hundred grams of solid carbondioxide or a few grams of an iodine compound are enough to crystallise a cubic kilometre of a supercooled cloud of water drops' (E. K. Fedorov, 1983, p. 293) (also see page 293). The second area of weather modification is **prevention of hailstorms.** The third area is of dispersal of low, supercooled clouds and fogs to clear airports in winter for smooth landing and take off of aircrafts. In all the cases enormous heat energy employed to induce precipitation, to prevent hails and to disprese and clear clouds and fogs is released and it causes additional heating of the lower layer of the atmosphere and thus changes the natural meteorological processes.

Withdrawal of groundwater for drinking water and irrigational purposes is a general practice in almost all the countries but some times the impact is so enormous that it becomes disastrous and pounds back on man and society. The example of Broklyn (Kings County, New York, U.S.A.) is sufficient to demonstrate environmental impact of groundwater withdrawal. The **pumping of water from beneath** the ground surface of **Brooklyn city for urban dwellers** resulted in the **formation** of a cavity of 5-mile diameter reaching a depth of 35 feet below sea level by 1936 (drilling continued for the first three decades of the 20th century). The water table dropped considerably due to withdrawal of groundwater at the rate of 75 million gallons per day on the one hand and poor replenishment of groundwater from natural sources (through infiltration of rainfall and snow melt) because of increasing urbanisation on the other hand. This resulted into the formation of big cavity beneath the city, consequently saline sea water leaked into the cavity and the wells became contaminated due to salty water which forced the city authorities to close down these contaminated wells. A few recharge wells were constructed and used water was allowed to return to the groundwate through these reacharge wells. This resulted int rapid rate of rise of water table by 1965. The trend o rise in water table continued upto 1970's and th water table rose to the foundations of building causing great damages to human construction Excessive withdrawal of groundwater also results i land subsidence (it may be pointed out that there wa no land subsidence in the case of Brooklyn a referred to above because of massive and stron rocks). A land subsidence of one metre to 3 metre has been reported in a few localities of San Joaqui velley in California because of drop in water tabl from 30m to 150m due to pumping of groundwate from the basins filled with alluvial sediments (A.N Strahler and A.H. Strahler, 1976, p. 127). The case of land subsidence due to withdrawal of groundwate have occurred in several localities and cities all ove the world e.g. Houston City (Texas, U.S.A., 0.3 t 1.0m), Mexcio city (ground subsidence from 4 to 7r between 1891 and 1959), Venice (Italy) etc. Groun subsidence also occurs due to mining activities.

Constructional activities, like consturction c dams and reservoirs, upset the equilibrium of th rocks below and thus is triggered off seismic event because the load of water of lakes and reservoir constructed behind the dams on major river increases hydrostatic pressure which causes disturbances in the underlying rocks., The earthquakes c Denver since 1962 (Denver, Colorado, U.S.A., du to pumping of fluids under pressure into disposa well upto the depth of 3600m and associated releas of strains within the already disturbed rocks), Lo Angles earthquakes of 1963 (California, U.S.A caused due to raising of the hydrostatic pressur through pumping of fluids into the oil field so tha the production of mineral oil could be increased, thi resulted into the movement of pre-existing fault and triggered off tremors which fractured the wall c the Baldwin Hills Reservoir), Lake Mead earthquake (Hoover Dam in Arizona and Nevada, U.S.A due to weight of accumulated water in the Mea Lake Reservoir), earthquakes occurring aroun Lake Kariba (on Zambezi river in Zambia), Koyan earthquake of 11 Dec. 1967 (Satara, Maharashtra India, due to weight of water in the Koyan Reservoir) etc.

Man changes the river regime and ecolog through flood control measures, reservoirs, construction of dykes and flood walls to restrict th water into river valleys, flood diversion systems an stream channelization (strengthening, shortening, widening, deepening of river channels to prevent seasonal overbank flooding).

(2) Indirect Impacts : The indirect impacts of man on the environment are not premeditated and planned and these arise from those human economic activities which are directed to accelerate the pace of economic growth especially industrial development. Though such economic activities may be economically important but the after-effects are certainly socially undesirable. The indirect impacts of human economic activities on the environment are not immediately noticeable because of time-lag because the effects of economic activities bring in slow rate of changes of moderate nature in a few components of the ecosystems and these changes take long time to cross the sensitivity of the system. Moreover, the indirect impacts are experienced after long time when they become cumulative. Sometimes, such effects are not reversible and therefore it becomes very difficult to identify and evaluate them. These effects may change the overall natural system and the chain effects some times become suicidal for human being. Majority of the indirect impacts of human activities on the environment are related to pollution and environmental degradation.

The release of toxic elements into the ecosyststem through their uses as insecticides, fertilizers etc. changes the food chains and food webs (e.g. introduction of D.D.T.). Similarly, the release of industrial wastes into stagnant water, rivers and seas contaminates water and causes several diseases and deaths of organisms and thus disturbs ecological balance (e.g. washing and dumping of tailings or waste sludges from factories, release and concentration of specks of asbestos, release of mercury in its toxic methyl form, leakage of crude oil from oil tankers, release of lead, mixing of different quantities of dissolved inorganic matter etc.).

The indiscriminate and excessive use of chemical fertilizers, insecticides, pesticides etc. and other chemicals not only pollute air, water and soils but also adversely affect food chains and hence all the biota. It is estimated that about 2000 chemicals are released to the atmosphere each year.

The accelerated rate of industrialization and usbanizaton has been responsible for severe air and water pollution all over the world. Several rivers in India have been so greatly polluted that they have become merely sewers e.g. the **Yamuna** at Delhi and Agra, the **Ganga** at Rishikesh, Haridwar, Kannauj, Kanpur, Allahabad (the Ganga at Allahabad has been so greatly polluted that 'sadhus'-saints of different sects refused to take both in the Ganga on the occasion of Mauni Amavasya in Januany, 2006 during annual 'Magh Mela'). The water of the Yamuna at Agra has become green and hence is called **green soup.** The **Damodar** has been so greatly polluted by the slurry of coal washeries and numerous industries located on its either banks that it is now called as **biological desert.** The heavily polluted **Gomati** at Lucknow has become biological disaster. The Periyar river once known for its medicinal miracle mainly for curing skin diseases now has become itself a sick river due to carrying of enormous pollution load released from more than 50 large and medium scale and 2500 small scale industrial units. The **Noyal river** in Tamil Nadu has been termed as a **dead river** because of heavy chemical pollution from 800 odd dyeing and bleaching units of Tirrupur industrial area located along the lower reaches of the river. These units use and discharge 90 million liters of water daily and thus besides polluting the river, these units have also polluted groundwater. The **Bhawani river,** a tributary of the Cauvery river, has been heavily polluted in Erode and Coimbatore districts of Tamil Nadu. The heavy pollution load of the **Cauvey,** besides agriculture including coffee plantation, is contributed by the effluents discharged from more than 60 industrial units in Karnatka and 1139 units in Tamil Nadu. The **Bhadar river** in Rajkot district of Gujarat has become the victim of chemical pollutants discharged from 1200 odd sari dyeing and printing units located in Jetpur, a small industrial town having more than 500 allied industrial units.

Urbanisation, industrial expansion and land use changes very often change **weather and climate** though in long-term perspective. Economic activities of man are capable of affecting the heat balance of the earth and its atmosphere which in turn transforms weather and climate at regional and global scales. In fact, man changes the atmospheric conditions through (i) changes in the natural gaseous composition of the atmosphere mainly in the lower part, (ii) changes in the water vapour content of the troposphere and the stratosphere through direct (cloud seeding) and indirect means (deforestation), (iii) changes and alteration of land surfaces (deforestation, mining, urbanisation etc.), (iv) introduction of aerosol in the lower atmosphere, (v) release of additional heat in the atmosphere (from urban and industrial sources) etc.

The burning of hydrocarbon fuels has increased the concentration of CO_2 in the atmosphere. The natural content of CO_2 in the atmosphere was fixed at 0.029 per cent or 290 ppm (part per million) before industrial revoluation (1750 A.D.) which increased to 368 ppm by2000 A.D. and it has been estimated by IPPC (Intergovernmental Panel on Climate Change) (2001 estimate) that CO_2 concentration would rise to 405-460 ppm by 2025, 445-640 ppm by 2050 and 540-970 ppm by the end of the 21st century if no effective and strict measures are taken to control the release of CO_2. The increase in CO_2 content of the atmosphere may change heat balance by increasing the level of sensible heat in the atmosphere because CO_2 allows more absorption of incoming short wave solar radiation and outgoing long wave terrestrial radiation. Release of chlorofluorocarbon in the atmosphere through the propellants used in spray can dispensers and fluids used in refrigerators and air conditioners and of nitrogen oxides emitted from the engines of supersonic jets (flying at the height of about 60,000 feet with a speed of more than twice the speed of sound) is capable of depletion of ozone. It may be pointed out that ozone gas in the atmosphere (ozone layer is concentrated mostly between the height of 15 km-35 km) absorbs ultraviolet rays of the sun and thus protects the earth from becoming too hot. Depletion in ozone layer means less absorption of ultraviolet rays and thus increase in the temperature at the earth's surface. Thus increase in air temperature through increased solar ultra-violet radiation due to decrease in the concentration of O_3 (ozone) would cause skin cancer, immuno-suppression in human body, decrease in photosynthesis, water use efficiency and crop yield. The marine environment would also suffer drastic damages as the productivity of phytoplankton would be reduced due to decrease in photosynthesis and therefore zooplankton feeding on phytoplakton would starve. This will also affect the mortality of larvae of zooplankton. The species composition of marine ecosystem may change as certain species are more vulnerable to ultraviolet radiation. Ultraviolet radiation also accelerates the photochemical processes that create urbaon smogs.

4

ECOLOGY

4.1 ECOLOGY : MEANING AND DEFINITIONS

Ecology, in a very simple term, is a science that studies the interdependent, mutually reactive and interconnected relationships between the organisms and their physical environment on the one hand and among the organisms on the other hand. Though the term **'ecology'** (oekologie or oecologie) was first coined and used by the German biologist, Ernst Haeckel in 1869, a few conceptual terms were already proposed to reveal relationships between organisms and their environment. For example, French zoologist, Isodore Geoffroy St. Hilaire used the term **'ethology'** in 1859, for the study of the relations of the organisms within the family and society in the aggregate and in the community. British naturalist St. George Jackson Mivart proposed the term **'hexicology'** for the study of the relations which exist between the organisms and their environment as regards the nature of the locality they frequent, the temperatures and the amounts of light which suit them, and their relations to other organisms as enemies, rivals, or accidental and involuntary benefactors'.

It may be pointed out that Darwin's concept of the **'evolution of species'** through natural selection involving interactions between biological species and habitat was the key stone of the formulation of various terms and concepts of inter-relationships between organisms and their physical environment in one way or the other. Thus, Ernst Haeckel coined the term **'oecology'** or **'oekology'** (derived from two Greek words, 'oikos' meaning house or dwelling as habitat and 'logos' meaning the study of) to understand the relationships between organisms and their environment. The following sentences of Haeckel (originally in German Language) throw light on various aspects of oecology (now ecology).

'By oecology we understand the science of oeconomy, of the domestic affairs of animal organisms. It enquires into the whole relation of animals with their inorganic and organic surroundings, and above all their friendly and hostile relations with such animals and plants as they come into direct or indirect contact with, or in short with all the involved interdependence that Darwin designated as the condition of the struggle for existence'. Ernest Haeckel, 1869, 1870.

'Oeconomy' was later on developed into **'economics'** which means the laws or rules of people's management of business while **'oecology'** became **'ecology'**, the science of laws and rules of the management of organic world. Haeckel defined the subject of **'oecology'** as the entire science of the relations of the organisms to the surrounding exterior world, to which relations we can count in the broader sense all the conditions of existence. These are partly of organic, partly of inorganic nature'.

The development of the subject of ecology was retarded during the late nineteenth century because scientific communities were actively engaged in either verifying or refuting the concept of evolution of species as presented by Charles Darwin in 1859. E. Warming associated the subject of 'ecology' to the study of plants and thus defined ecology as 'the study of organisms in relation to their environment' (E. Warming, 1895, 1905). Ecology was cconisdered by American ecologist Frederick Clements (1916) as 'the science of community' while Charles Elton defined ecology as 'a scientific natural history'. Thus the science of ecology was endowed with two overlapping areas of study e.g. (i) the study of organisms in relation to their environment, and (ii) the evolutionary history of the organisms.

British ecologist Macfadyen (1957) emphasised to discover the principles which govern the relationships between plants or animals and their environment while K. Friederichs (1958) defined ecology as 'the science of living beings as members of the whole of nature' but he ignored the effects of the organisms on environment and those of the environment on the organisms. F. Fraser Darling (1963) broadened the field of ecology by defining the subject as 'the science of organisms in relation to their total environment, and the inter-relationships of organisms inter-specifically and between themselves'. This definition of ecology led to the development of two approaches to the study of ecology and its divisions into two branches viz. (i) **'autecology'** wherein ecological relations of individual species in a given ecosystem are studied, and (ii) **'synecology'** which is the study of plant communities in relation to their habitats of a given ecosystem.

More recently, the concept of ecology has been extended 'to the corresponding range of phenomena, research and problems. In that connection 'ecology' has been quite logically extended as well to the field of the interaction of society and its physical environment (Y.P. Trusov, 1983).

E.P. Odum (1963, 1964, 1969, 1971) pleaded for remodelling the conventional definition of ecology (the science of inter-relationships between organisms and environment) on the ground that biotic and abiotic components of nature are not only interrelated in reciprocal manner but these two components also function in an orderly manner as a definite system. So, Odum presented a new definition of ecology as 'the study of the structure and function of ecosystems' or the 'study of structure and function of nature'.

It may be summarized that : 'ecology is a science that studies interrelationships between biotic and abiotic components of a natural ecosystem on one hand and among organisms on the other hand'. Savindra Singh

4.2 AIMS AND SCOPE OF ECOLOGY

The scope of ecology and its aims have expanded enormously with the development of ecological concepts and thoughts consequent upon growing interests in man-environment relationships due to increasing pressure on natural/ecological resources to sustain and enhance economic development in view of ever-increasing human population. In fact, 'the traditional view of ecology as the science of living things in relation to their environment has helped to place it in a valuable strategic position from which it can make important contributions to their environmental management (C.C. Park, 1980).' Thus ecology is not only confined to biological sciences from where it has come out but it has reached the whole society and many branches of knowledge. 'Indeed, to many people ecology is almost synonymous with conservation and the environment' (C.C. Park, 1980) because 'ecology not only studies various aspects of plants and animals but the whole society of all biota as ecology has ceased to be a synthesised branch of biology... it has become a view point '(K. Friederichs, 1958). Ecology now lays more emphasis on the study of unity and balance of environment or biospheric ecosystem. Ecology has been viewed as 'a state of the mind' by J. Maddox (1972) on the basis of its holistic nature, 'as a unifying social movement' by R.F. Dasmann (1974), while N. Simon and P. Gerondet (1970) have highlighted the potential contribution of ecology to environmental and ecological problems and relevance of ecological studies to social and economic stability and balance and they have suggested that ecology should not be confined only to abstract scientific discipline but should rise above to solve the environmental problems which the human society is confronted with.

Thus, the scope of ecology has been extended from the scientific study of mutual relationships of biotic and abiotic components of the whole biosphere or part thereof to the environmental problems in terms of environmental degradation and ecological crises arising out of increased human impacts on natural/ecological resources through advanced modern technologies aimed at accelerated rate of economic development to meet the demands of ever increasing population at global and regional levels. Thus, there has been marked shift in the emphasis of ecological studies in terms of man-environment relationships atleast from geographical view points.

Historically, the development of ecology in terms of the scope of the subject, major areas of interest, aims and objectives and approaches to the study of various aspects of ecology, may be divided into four phases as follows :

(i) **Phase One,** representing the period upto First World War, was dominated by the attempts to define ecology mainly based on reciprocal relationships between the organisms and their environment, to search and identify fundamental units of vegetation, to develop methods for vegetation classification, to trace the evolutionary history of plants and animals as influenced by Darwinian concepts of evolution of species, to explain the relationships of plants and animals in relation to difference of habitats etc.

(ii) **Phase Two,** representing the inter-war period (between the two world wars), was characterised by more rigorous and serious study of relationships between vegetation characteristics and physical conditions of habitat rather than the surveying, mapping and classification of vegetation; development of scientific methodologies based on laborarory analysis, pollen analysis, application of statistical techniques etc., diversification of the feld of ecology (i.e. besides natural terrestrial plant communities, the studies of plant communities of fresh water and seas and oceans and animal communities were brought under the domain of ecology); attempts to study ecological stability and various aspects of interactions between biotic and abiotic components etc.

(iii) **Phase Three** (from the Second World War to 1960) was characterised by the introduction of system analysis in ecological studies. The complex relationships between organisms and their physical environment were attempted through ecosystem studies based on more rigorous experimental results. Major ecological processes became the focal theme of ecological studies.

(iv) **Phase Four** or the **Modern Phase** (since 1960) is characterised by much diversification and specialization of themes of ecology. The most outstanding field of interest is the emergence of applied ecology which envisages the role of ecology in nature conservation and environmental management from ecological view points for the solution of socio-economic and political problems and for the formulation of environmentally sound social planning programmes. 'In particular the concept of niche theory, the ecosystem energy flow, material recycling, tolerance limits and successional change have been employed in a range of different planning context' (C.C. Park, 1980).

The major themes and areas of ecological studies at ecosystem level (based on the basic tenet that ecosystem is a fundamental ecological unit) include the holistic view of the characteristics of abiotic (physical) and biotic components which form an ecosystem, the functioning of ecosystem through energy flow and bio-geochemical cycles involving the cycling and recycling of organic and inorganic substances through various components of ecosystem, photosynthesis, food chains and food webs, ecological pyramids, ecosystem productivity, limiting factors of productivity, ecological stability, evolution of plant and animal species, extinction of species, contemporary evolution, successional development of plant communities, spatial distribution of plants and animals and biome types, ecological variations at global and regional scales, man-induced ecological changes, environmental controls of ecological variations, ecological resources, ecological imbalance and environmental degradation and pollution and remedial measures thereof, resource management, and ecological basis of environmental management. The most significant thrust area of vital interest is the study of man-environment relationships specially the impacts of man on environment which adversely affect the environmental and ecological processes causing environmental degradation and ecological imbalance and the formulation of ecologically sound environmental planning and management.

The concept of ecology now has been extended from single phenomenon (plant ecology, animal ecology) to set of phenomena occupying a definite space in the biosphere at a definite time interval e.g. forest ecology, grassland ecology, lake ecology, river ecology, agricultural ecology, industrial ecology, rural ecology, urban ecology, population ecology, social ecology etc. The main sub-fields of ecology are outlined in the following next subsection.

4.3 SUB-DIVISIONS OF ECOLOGY

The field and the scope of ecology have changed during various phases of methodological development of the subject and therefore major subdivisions of ecology should be determined according to different approaches which include taxonomic affinities, habitat, levels of organisation and modern social and economic situations at global and regional levels.

1. Sub-division Based on Taxonomic Affinities

In the beginning, ecology was exclusively associated with biological sciences-botany and zoology and thus plants (botany) and animals (zoology) were studied separately. This approach led to the division of ecology into (i) **plant ecology** and (ii) **animal ecology**. Each division was further sub-divided into micro-divisions based on specialized studies of individual components e.g. plant ecology into oak ecology, pine ecology etc. and *animal ecology* into insect ecology, bacterial ecology, fish ecology etc. It may be pointed out that these two groups of biota are so inseparable and interrelated that it is not advisable to isolate one individual from the groups of organisms for the ecological study of single species and therefore this subdivision is not acceptable at present on the ground that there is complex interrelationships and interdependencies of all types of organisms with their habitats (physical environment).

2. Sub-divisions on the Basis of Habitat

The basic tenet of the division of ecology on the basis of habitat is that there are variations in habitats in terms of their physical characteristics (e.g. topography, soils, insolation and temperature, water, minerals, weather and climate etc.) and therefore there are definite effects of a particular habitat on the organisms and general characteristics of biotic communities vary from one habitat to the other. This approach of ecological study led to the development of **'habitat ecology'**. The habitat ecology is further sub-divided on the basis of habitats and their relationships with the organisms inhabiting a particular habitat into **forest ecology, grassland ecology, fresh water ecology, estuarine ecology, island ecology, marine ecology, coral reef ecology** etc.

3. Sub-division on the Basis of Levels of Organisation

The third approach to ecological studies is to study either individual organisms or groups of organisms of a particular ecosystem. In other words, ecological studies may be accomplished at two levels viz. (i) study of ecological relationships between the species, and (ii) ecological relationships within the ecosystem involving all the organisms present therein. This approach led to the development of (i) **autecology**, and (ii) **synecology. Autecology** is the study of relationships of individual species to its environment. Thus it is apparent that autecological approach rests on individual species as fundamental units of study wherein various aspects of species like geographical distribution, morphological and taxonomic position, life cycle and succession and ecological factors which affect different stages of growth and development of species are studied. **Synecology** is the study of complex interrelationships of groups of organisms known as biological community because organisms (plants, animals and micro-organisms) affect each other in reciprocal manner and interact with the habitat or natural environment. Thus the fundamental unit of study is biological community rather than individual organisms. Further, synecology is subdivided into **'population ecology'** (the study of interactions of individuals-population-|of single species with each other), **'community ecology'** (the study of interrelationships and interdependencies of groups of individuals of different species-plants and animals together), **'biome ecology'** (the study of interactions and interrelationships of more than one biological communities in different stages of succession under similar climiatic condition of the area concerned) and **'ecosystem ecology'** (the study of interactions and interrelationships of all organisms among themselves and with their environment).

Thus the fundamental unit of study is an ecosystem area having both biotic and abiotic (physical) components. It is ecosystem ecology which forms the basis of studies in environmental geography.

4.4 ECOLOGICAL CONCEPTS AND PRINCIPLES

There are certain basic fundamental principles which govern the various aspects of organisms e.g. evolution and distribution of plants and animals, extinction of species, biological succession, consumption and transfer of energy in different components of biological communities, cycling and recycling of organic and inorganic substances through various bio-geochemical cycles, life cycle of organisms, interactions and interrelationships among the organisms and between organisms and physical environment, etc. These concepts and principles may be analysed on structural and functional bases separately but both bases may be combined together if the ecological studies are considered at the level of ecosystem which has been recently accepted as fundamental ecological unit. The following fundamental concepts and principles of ecology in terms of ecosystem may be highlighted.

(1) **Ecosystem is a fundamental unit** of ecological study because it comprises both biotic and abiotic components. In other words, ecosystem being a monistic concept, brings physical environment, plants and animals together in a single framework which facilitates the study of interactions between biotic and abiotic components. Ecosystems are well structured and organised units through biotic and abiotic components. Ecosystems are also functional units wherein two biotic components are of major significance i.e. (i) The **autotrophic components,** comprised of green plants prepare food through photosynthesis and use inorganic substances. These are self feeding and provide food energy to other biological communities, (ii) The **heterotrophic components** (animals and micro-organisms) use, rearrange and decompose organic substances which are made available from the primary produce of autotrophic components.

(2) At the largest scale, the whole biosphere becomes an ecosystem. The **biotic and abiotic components of biosphereic ecosystem are intimately related to a series of large-scale cycle mechanisms** e.g. water cycle, chemical elements cycle, sediment cycle and unidirectional flow of energy. These cycles help in the transfer of energy, water, chemical elements and sediments in various components of the biosphere.

(3) **'Sustained life on the earth is a characteristic of ecosystem,** not of individual organisms or population' (D.B. Botkin and E.A. Keller, 1982).

(4) M.J. Holliman (1974) has formulated the following four **'environmental principles'** of holistic nature of natural environment which largely affects the biological communities in a biospheric ecosystem.

(a) 'Nothing actually disappears when we throw it away' because all the materials are rearranged and cycled and recycled through a series of cyclic pathways in the natural environment.

(b) 'All systems and problems are ultimately if not intimately inter-related. It does not make sense to squabble over which crisis is most urgent; we cannot afford the luxury of solving problems one by one. That is both obsolete and ecologically unsound anyway'.

(c) 'We live on a planet earth whose resources are finite'.

(d) 'Nature has spent literally millions of years refining a stable ecosystem'.

(5) **The physical and biological processes follow the principle of 'uniformitarianism'** which states that same physical (right from the origin of planet earth and its atmosphere) and biological (since the origin of first organism) processes which operate today, operated in the past not necessarily with constant magnitude and frequency with time and will operate in future but 'at rates that will vary as the environment is influenced by human activity' (D.B. Botkin and E.A. Keller, 1982).

(6) **Natural hazards affect adversely the biological communities** in general and man in particular. When biological processes are associated with physical events, yet severe hazards are created. For example, after floods mainly in urban areas, water is contaminated by bacteria and thus diseases spread at faster rate.

(7) **All living organisms and physical environment are mutually reactive.** In other words, living organisms interact among themselves and affect each other on the one hand and living organisms and physical environment are interrelated through reciprocal interactions and these affect each other on the other hand. The varying degrees of interactions

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among organisms, at both inter-and intraspecific levels, are positive, negative and some times neutral.

(8) **Ecosystem functions through the input of energy mainly solar radiation** which is trapped by green plants (primary producers) and is used to prepare food (chemical organic matter) through the process of photosynthesis. Thus, the solar radiation is the main driving force of the ecosystem. **Energy flow** (transfer of organic molecules) **is unidirectional** (passes through various trophic levels) **and is non-cyclic.** Ecosystem energetics or energy flow also helps in the circulation of chemical substances (nutrients)within the ecosystem. There is progressive loss of energy by respiration of organisms through increasing trophic levels. The energy pattern and flow are governed by the following first and second laws of thermodynamics.

Law I—In any system of constant mass, energy is neither created nor destroyed but it can be transformed from one type to another type. The energy inflow or input in a system is balanced by energy outflow.

Law II—When work is done, energy is dissipated and the work is done when one form of energy is transformed into another form.

Thus, energy is transferred from one trophic level to the next higher trophic level but organisms at higher trophic levels receive energy from more than one trophic level (in a natural ecosystem, there are four trophic levels viz. trophic level one represented by autotrophic green plants, trophic level two represented by herbivorous animals, trophic level three represented by carnivorous animals and trophic level four having omnivorous animals including man). R.L. Lindeman (1942) has formulated four principles about the relationships between trophic levels within a natural ecosystem.

Principle I : As the distance between the organisms of a given trophic level and the initial source of energy (trophic level one) increases, the probability of the organisms to depend exclusively on the preceding trophic level for energy decreases. In other words, the organisms at trophic levels three and four do not depend for energy only on trophic levels two and three respectively rather they receive energy from more than one source (trophic level) which means that organisms at trophic level three and beyond tend to be 'generalists' rather than 'specialists' in terms of their feeding habit.

Principle II : The relative loss of energy due to respiration is progressively greater to higher trophic levels because the species at higher trophic levels being relatively larger in size have to move and work for getting food and therefore more energy is lost due to respiration.

Principle III : Species at progressively higher trophic levels appear to be progressively more efficient in using their available food supply, because increased activity by predators increases their chances of encountering suitable prey species, and in general predators are less specific than their prey in food preferences.'

Principle IV : 'Higher trophic levels tend to be less discrete than the lower ones' because the organisms at progressively higher trophic levels receive energy from more than one source (trophic level) and are 'generalists' in their feeding habit and they are more efficient in using their available food supply.

Principle V : 'Food chains tend to be reasonably short. Four vertical links is a common maximum' because loss of energy is progressively higher for higher trophic levels and species at higher levels tend to be less discrete.

(9) The chemical (inorganic) and organic substances are circulated among the various components of the biosphere through a series of closed system of cycles collectively known as **'biogeochemical cycles'** in such a way that total mass of these substances remains almost the same and are always available to biotic communities. **The functioning of biogeochemical cycles is cyclic** through various simple and complex pathways and the substances are distributed, rearranged, cycled and recycled through the gaseous (atmospheric), biotic and sedimentary phases of reservoirs of these substances. These substances (both inorganic and organic) are required by the organisms as nutrients for the sustenance of their lives.

(10) **The ecosystem productivity** (referred to as the rate of growth of energy or organic matter per unit time by autotrophs at trophic level one) depends on two factors : (i) the availability of the amount of solar radiation to the primary producers (autotrophs-green plants) at trophic level one, and (ii) the efficiency of plants to convert solar energy into chemical energy. **There is marked positive correlation between primary productivity and solar radiation.** The progressive decrease in solar radiation towards

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the poles is closely followed by decrease in primary productivity in that direction provided that other factors controlling productivity also change in the same direction. The limiting factors, besides solar radiation, which control the ecosystem productivity, include abiotic factors (rainfall, depth of water and above all climate and chemical factors-nutrients) and biotic factors (mode of interaction between various populations such as mutualism, competition, commensalim, neutralism, parasitism, predation etc. and internal instinctive control mechanisms within the populations such as social organisation, territoriality and social hierarchies).

(11) **The 'normal' or 'uneventful' ecosystem attains its stability** (which means balance between production and consumption of each element in the ecosystem or balance between input and output of energy and normal functioning of different biogeochemial cycles and stable condition of concentration of all elements) **through 'homeostatic mechanisms'**. There is inbuilt self-regulating mechanism in a natural ecosystem through which any change caused by external factors in the ecosystem is counter-balanced by the responses of the system to the change in such a way that ultimately ecosystem or ecological stability is restored. The ecological diversity and complexity enhance the ecosystem/ecological stability. The ecological concept of diversity/stability has been illustrated in the following manner :

(a) Increase in the diversity of food webs promotes ecosystem stability because increased food web diversity increases the resilience of the system to outside invasions of exotic orgnisms and reduces the fluctuations in the population within a given ecosystem.

C.S. Elton (1958)

(b) The ecosystem stability increases with increase of number of links in the food web because a large number of interacting feeding links provides alternative channels for energy flow and thus is generated a wide variety of adjustment of the population to environmental changes and stresses within the ecosystems.

P.H. MacArthur (1955)

(c) High species diversity of a mature ecosystem representing a **'climax community'** is related to more stability of natural ecosystem because as the community succession operates, **'homeostatis'** increases due to more protection available to the member of the community against external environmental change.

E.P. Odum

(12) **Ecosystem instability results when an ecosystem becomes unable to adjust with environmental changes.** This so happens when the environmental changes exceed the resilience or the capacity of the ecosystem to adjust with changed environmental conditions.

(13) **Evolution of species epitomises the inherently dynamic nature of ecosystem.** Charles Darwin (1859) postulated the principles and mechanisms of evolution of species by the process of **'natural selection'** wherein heritable variations in the populations (population means a community of individuals of sexually-reproducing species) form the basis of evolution of species. The following are the main principles of natural selection (based on H. Robinson's interpretation of Darwinian theory of origin of species) as advanced by Charles Darwin :

(a) There are heritable variations in the individuals of species. Though such heritable variation is small but it is very significant because it forms the very basis of evolution of species.

(b) Heritable variations provide certain characteristics which become advantageous to some individuals to become more efficient and better able to survive in their environment for the struggle of their lives.

(c) Such advantageous characteristics conferred on an organism may provide better chance of survival and reproduction.

(d) When these advantageous characteristics are passed on by the organisms to their offsprings, the succeeding generations become superior and further efficient in the struggle for existence and survival.

(e) The individuals of the species, which lack the advantageous characteristics to stand up to their environmental conditions in their struggle for life and existence, are most likely eliminated by competition from the better equipped superior members (which have acquired advantageous characteristics) of their species.

(f) During the struggle for existence between organisms, the winner leads to evolution of species and the loser leads to extinction. This so happens when the struggle takes place between closely related species.

(g) The process of natural selection (as referred to above) and adaptation to environmental conditions leads to gradual modification and diversification of species over long period of time. Such variations in species increase progressively with each succeeding generation of species and evolution of species continues.

(14) De Vries challenged the Darwinian concept of progressive evolution of species on the ground that sometimes the offsprings differ from their parents so markedly that a new species is evolved within a single generation. There is spontaneous and abrupt evolution of species. The process of spontaneous evolutionary change is termed as 'mutation' which is believed to introduce inheritable variations in a species. Such inheritable variations can be spread by inter-breeding. T. Dobzhansky (1950) has presented the following basic elements of mutation :

(a) 'The mutation process furnishes the raw materials of evolution'.

(b) Numerous gene patterns are produced during the process of sexual reproduction.

(c) 'The possessors of some gene patterns have greater fitness than the possessors of other (gene) patterns in available environment'.

(d) The frequency of superior gene patterns is increased by the process of natural selection while the inferior gene patterns are suppressed.

(e) 'Groups of some combinations of proven adaptive worth become segregated into closed genetic system, called species.'.

(Quoted by C.C. Park, 1980)

(15) **'Reproductive isolation' is another aspect of evolution of morphologically differentiated populations of species.** The process of 'isolation allows newly formed genetic patterns to avoid being vitiated by continuous cross-breeding with neighbouring individuals or population' (P.A. Furley and W.W. Newey, 1983). In other words, there are certain obstacles or barriers (comprising external factors such as geographical isolation, ecological isolation, seasonal isolation, mechanical isolation etc. and internal factors, which prevent the formation of hybrids after cross-fertilization) which prevent gene exchange between morphologically different populations. Reproductive isolation is considered to be the most crucial step in the evolution of new species because 'without isolation, new species might never evolve anywhere'.

(S. Carlquist, 1974)

(16) **The concept and principle of succession are very important in ecology as there is successional development of species mainly vegetation communities.** Succesion simply means the entire process of directional and sequential change of either plant community (groups of plants adapted to a particular habitat) or the whole ecosystem through time. F.E. Clements (1961) postulated the concept of vegetation succession which he defined as the directional and sequential development of plant community in an orderly and predictable sequence along definite pathway towards predictable end situations. According to F.E. Clements there are five sequential phases in the successional development of vegetation in a given habitat with available environmental conditions.

(a) **Phase of nudation** or the creation of new area devoid of vegetation.

(b) **Phase of migration** begins with the arrival of seeds into the newly created bare area.

(c) **Phase of ecesis,** when the plant seeds are established in the newly created bare area through germination and plant growth.

(d) **Phase of reaction,** when there is competition between the established plants on the one hand and interaction between plants and the physical environment of the habitat on the other hand.

(e) **Phase of stabilization,** when there is equilibrium condition of population of plant species in harmony with the environmental conditions of local and regional habitats.

(17) The **transitional stages of sequential changes from one vegetation community to another vegetation community are called 'sere'.** The 'sere' is complete when the succession of vegetation community after passing through different phases culminates into equilibrium condition. The vegetation community developed at the end of succession is called **'climax vegetation', 'climax community'** or **'climatic climax'** (due to dominant control of climate on the evolution and development of vegetation). F.E. Clements (1916) has identified two basic forms of succession : (i) **Primary succession** : refers to developmental sequence of vegetation in those bare areas where there was no vegetation earlier. Such

areas may be newly emerged sea floor, cooled and solidified basaltic surface due to recent lava flow, exposed lake bed due to drying of water, newly formed sand dunes, flood plains formed by recent alluvia, heaps of debris accumulated by man etc. (ii) **Secondary Succession :** Developmental sequence of vegetation in those areas which had vegetation cover but now have been rendered nude due to destruction of vegetation (either parly or completely) either by natural processes (lava flow, drought, glaciation, natural firest fires through lightning, severe storms, floods etc.) or by human interference (intentional burning of vegetation, and land use changes, mass felling of trees and overgazing etc.).

(18) **Besides community succession, the ecosystem also undergoes the process of successional changes.** According to E.P. Odum (1962) 'ecological succession is one of the most important processes which results from the community modifying the environment'. According to R.H. Whittaker (1953) the successional development of ecosystem is characterised by four major changes in the eocystem viz. (i) Progressive increase in the complexity and diversity of community. (ii) Progressive increase in the structure and productivity of ecosystem, (iii) Increase in soil maturity, and (iv) Increase in relative stability and regularity of populations within the ecosystem and stability of the ecosystem itself.

(19) **Man, being an active agent of environmental change, modifies the ecosystem through the exploitation of natural resources.** He reduces the ecological diversity and complexity of the ecosystem by removing a host of biotic communities for different purposes. The disruption of 'climax vegetation' and ecosystem stability is caused by man through (i) purely destructive actions (forest clearance through mass felling and extensive burning), (ii) introduction and establishment of new types of vegetation in the ecosystem which were previously not present in that ecosystem (for example, natural forest replaced by food crops), (iii) introduction of species of plants and animals into the areas beyond their native places, (iv) farming practices (for example, by allowing the economic plants, such as food crops, to grow while destroying the unwanted or uneconomical plants, such as weeds and bushes through the application of herbicides and pesticides), (v) habitat changes, and (vi) constructional actions (such as roads, settlements, urbanisation, field drainage, canals etc.).

(20) **The ultimate goal of ecological study is to preserve ecological resources by maintaining the ecological diversity and ecosystem stability.** 'Preserving diversity in a world of rapidly shrinking land resources will require a prompt and universal response on an appropriate application of ecological knowledge. Every nation should possess an inventory of its biological endowment' (J. Terborgh, 1974) for the purposeful ecological and environmental management for future generation of human society to which the present society has to bear the obligation.

The **ecological principles** may be summarised as follows :

- natural ecosystem is a fundamental unit of ecological study.
- at the largest scale the whole of biosphere becomes an ecosystem, the biotic and abiotic components of which are intimately related.
- 'sustained life on the earth is a characteristic of ecosystem'.
- 'nothing actually disappears when we throw it away' because all the materials are rearranged and cycled and recycled through a series of cyclic pathways (geobiochemical cycles) in the natural ecosystem.
- the natural resources are finite and are public property.
- 'nature has spent millions of years to refine a stable ecosystem.'
- the physical, chemical and biological processes follow the principle of uniformitarianism.
- all living organisms and physical environments are interdependent and mutually interactive.
- ecosystem functions through the input of mainly solar energy.
- there is unidirectional flow of energy through various trophic levels in natural ecosystem.
- as the distance between the organisms of a given trophic level in a natural ecosystem and the initial source of energy (trophic level one of the green plants) increases the probability of the organisms to depend exclusively on the preceding trophic level for energy decreases.
- the relative loss of energy due to respiration increases with higher trophic levels.

- the chemical (inorgnaic) and organic substances are circulated among the various components of the biosphere through a series of closed system of cycles collectively known as geobiochemical cycles.
- the ecosystem productivity and ecological production depend on (i) the availability of the amount of solar energy to the primary producers (autotrophic green plants) at trophic level one, and (ii) the efficiency of plants to convert solar energy into chemical (food) energy.
- there is marked positive correlation between solar radiation and primary ecological productivity.
- the natural ecosystem attains its stability through homeostatic mechanism.
- increase in the diversity of food webs promotes ecosystem stability and ecological balance.
- ecosystem instability and ecological imbalance result when an ecosystem becomes unable to adjust with environmental changes, whether natural or anthropogenic.
- evolution of species represents the inherently dynamic nature of ecosystem, wherein there is gradual speciation by the process of 'natural selection' and 'adaptation' (Darwin) but there is also spontaneous and abrupt evolution of species through the process of 'mutation' (De Vries).
- 'reproductive isolation' is another aspect of evolution of morphologically differentiated populations of species.
- there is successional development of vegetation community through the phases of nudation, migration, ecesis, reaction and stabilization.
- the vegetation community developed at the end of succession becomes 'climax vegetation' or 'dimax community' or 'climatic climx'.
- besides community succession, the ecosystem also undergoes the process of successional changes.
- the ultimate goal of ecological study is to conserve and preserve ecological resources by maintaining the ecological diversity (biodiversity) and richness, and ecosystem stability.

4.5 ECOLOGICAL NICHE

The concept of **'ecological niche'** was first introduced by J. Grinel in 1917 but it was developed by Charles Elton in the year 1927. G.E. Hutchinson proposed more biophysical definition of ecological niche. The term of ecological niche has been used in different contexts by the ecologists such as ecological niche as a particular function played by a specific species in a given ecosystem (role of species); as a habitat of specific species in a given ecosystem representing total environmental condition (habitat factor) or as a distributional pattern of species in ecosystem (community role) etc.

It may be mentioned that in a natural ecosystem there are several species of plant and animal communities and species of each community play different roles in getting food and thus each community is confined to a certain locality. Such locality having ideal environmental conditions which are suitable for the survival of specific species is called niche. The species of a given niche may not survive in other niches. It is also important to note that there are numerous niches in a given natural ecosystem.

Thus, ecological niche may be defined as 'the functional role and position (micro-habitat) of species in its ecosystem, including what resources it uses, how and when it uses the resources, and how it interacts with other species'.

W.P. and M.A. Cunnigham, 2003

There are temporal changes in ecological miche as the species develop new ways to exploit resources. Thus, it becomes difficult for two species to inhabit the same niche. In such cases the **law of competitive exclusion** works, which states that 'no two species will occupy the same niche and compete for exactly the same resources in the same habitat for very long' (Cunnigham and Cunnigham, 2003). In such situation, one species may adopt a few alternative paths e.g. (i) either one species may migrate to new niche, or (ii) may become extinct, or (iii) may change physiological behaviour for the competition of same resources. The process of minimization of competition for resources in called **resource partition** which 'can allow several species to utilize different parts of the same resource and coexist within a single habitat (niche) (Cunnigham and Cunnigham, 2003)'.

The ecosystem stability depends upon the diversity of niche. In fact, the greater the niche diversity, the more is ecosystem stability because of larger number of pathways for the flow of energy and less fluctuation of species population. The ecosystem becomes unstable if one or more species are eliminated because then the niche becomes empty and energy pathways are remarkably reduced.

S.J. McNaughton and L.L. Wolf (1970) have outlined the following characteristic features of ecological niche :

- The number of species in a niche of a natural ecosystem becomes large with high abundance of resources and vice versa.
- With the increase in the number of species of a community the average width of niche of species within that community decreases (and hence availability of resources also decreases).
- Dominant species occupy extensive and broader ecological niche in comparison to less dominant species because they are specialists as they have adapted themselves to a particular niche having single dimension of environmental variation.
- More species may be added to the ecosystem by 'compression of existing niches'.
- If the sites (habitats or locations) are most equitable having equitable distribution of resources, the dominance of a particular species becomes minimum.

Quoted by C.C. Park, 1980

According to S.A. Whittaker, and R.B. Root (1973) ecological niche are affected by 3 types of variables e.g. inter-ecological niche are affected by 3 types of variables e.g. (1) inter-community variables or habitat variables, (2) intra-community variables or niche varibles, and (3) population response variables. (1) **Habitat variables** include physical factors such as relief (elevation), slope, soil moisture, soil fertility etc. The community gradient (species variations as determined by physical factors) as determined by physical environmental factors are also important factors which determine the nature of a particular ecological niche. (2) **Niche variables** include height of the location above ground surface, relationship to intracommunity pattern (food habit, food chain etc.), seasonal and diurnal time, number and size of prey, and ratio between number of animals and plant food etc. (3) **Population response variables** include population density (of both plants and animals), coverage of species, frequency of feeding, success of reproduction, fitness of animals etc.

(In C.C. Park, 1980)

5

ECOSYSTEM

5.1 ECOSYSTEM : MEANING AND CONCEPT

The term **'ecosystem'** was first used by **A.G. Tansley** in 1935 who defined ecosystem as 'a particular category of physical systems, consisting of organisms and inorganic components in a relatively stable equilibrium, open and of various sizes and kinds'. According to Tansley the ecosystem is comprised of two major parts viz. biome (the whole complex of plants and animals of a particular spatial unit) and habitat (physical environment) and thus 'all parts of such an ecosystem-organic and inorganic, biome and habitat-may be regarded as interacting factors which, in a mature ecosystem, are in approximate equilibrium, it is through their interactions that the whole system is maintained' (A.G. Tansley, 1935). F.R. Fosberg (1963) has defined ecosystem as 'a functioning, interacting system composed of one or more living organisms and their effective environment, both physical and biological'.

According to R.L. Lindeman (1942) the term ecosystem applies to 'any system composed of physical-chemical-biological processes, within a space-time unit of any magnitude'. In E.P. Odum's view (1971) 'living organisms and their non-living (aboitic) environment are inseparably interrelated and interact upon each other. Any unit that includes all of the organisms (i.e. the community) in a given area interacting with the physical environment so that a flow of energy leads to clearly defined trophic structure, biotic diversity and material cycle (i.e. exchange of materials between living and non-living parts) within the system is an ecological system or ecosystem'.

According to A. N. Strahler and A.H.Strahler (1976), 'the total assemblage of components interacting with group of organisms is known as ecological system or more simply, an ecosystem. Ecosystems have inputs of matter and energy, used to build biological structure (the biomass), to produce and to maintain necessary internal energy levels. Matter and energy are also exported from an ecosystem. An ecosystem tends to achieve a balance of the various processes and activities within it'.

Based on the contents of above definitions of ecosystem provided by various scientists it may be pointed out that 'ecosystems are therefore unities of organisms connected to one another and to their environment' (P.A. Furley and W.W. Newey, 1983), 'and the ecosystem is thus the sum of all natural organisms and substances within an area, and it can be viewed as a basic example of an open system in physical geography' (C.C. Park, 1980). Stressing the importance of ecosystem C.C. Park further says that 'ecosystems are regarded by many ecologists to be the basic units of ecology because they are complex, interdependent and highly organised systems, and because they are the basic building blocks of the biosphere'.

'In a more lucid style and simple term an ecosystem may be defined as a fundamental functional unit occupying spatial dimension of 'earth space ship' characterised by total assemblage of biotic community and abiotic components and their mutual interactions within a given time unit'. (Savindra Singh, 1991)

Properties of Ecosystems

The ecosystems are characterized by the following basic properties :

- Ecosystem of any given space-time unit represents the sum of all living organisms and physical environment.
- It is composed of three basic components viz. energy, biotic (biome) and abiotic (habitat) components.
- It occupies certain well defined area on the earth-spaceship (spatial dimension).
- It is viewed in terms of time-unit (temporal dimension).
- There are complex sets of interactions between biotic and abiotc components (including energy component) on the one hand and between and among the organisms on the other hand.
- It is an open system which is characterised by continuous input and output of matter and energy.
- It tends to be in relatively stable equilibrium unless there is disturbance in one or more controlling factors (limiting factors).
- It is powered by energy of various sorts but the solar energy is the most significant.
- It is a functional unit wherein the biotic components (plants, animals including man and micro-organisms) and abiotic (physical environment) components (including energy component) are intimately related to each other through a series of large-scale cyclic mechanisms viz. energy flow, water cycle, bio-geochemical cycle, mineral cycle, sediment cycle etc.
- Ecosystem has its own productivity which is the process of building organic matter based on the availability and amount of energy passing through the ecosystem. The productivity refers to the rate of growth of organic matter in an aeral unit per time-unit.
- Ecosystem has scale dimension i.e. it varies in spatial coverage. It may be as small as a cowshed, a tree or even a part of a tree having certain micro-organisms. The largest unit is the whole biosphere. Thus the ecosystems may be divided into several orders on the basis of spatial dimension. It is clear that 'the ecosystem is a convenient scale at which to consider plants and animals and their interaction because it is more localised and thus more specific than the biosphere in its entirety, and it includes a sufficient wide range of individual organisms to make regional generalizations feasible and valuable' (C.C. Park, 1980)..
- There are different sequences of ecosystem development. The sequence of ecosystem development in term of a particular suite of physical and chemical conditions is called as 'sere'. A 'sere' represents the development of a series of sequential successions starting from primary succession and culminating into the last succession in a sere as **'climax'** or **'climatic climax'** which is the most stable situation of an ecosystem. Thus, the study of ecosystem development may help in environmental planning from ecological point of view.
- Ecosystems are natural resource systems.
- Ecosystem concept is monistic in that environment (abiotic component), man, animals, plants and micro-organisms (biotic components) are put together in a single framework so that it becomes easy to study the patterns of interactions among these components.
- It is structured and well organized system.
- Ecosystem, for convenience, may be studied as a 'black box model' by concentrating on the study of input variables and related output variables while the input variables may be ignored to reduce the complexity.

5.2 TYPES OF ECOSYSTEMS

Ecosystems may be identified and classified on various bases, with different purposes and objectives as outlined below :

(1) On the basis of habitats : The habitats exhibit physical environmental conditions of a particular spatial unit of the biosphere. These physical conditions determine the nature and characteristics of biotic communities and therefore there are spatial variations in the biotic communities. Based on this premise the world ecosystems are divided into two major categories viz. (A) **terrestrial ecosystems,** and (B) **aquatic ecosystems.** There are further variations in the terrestrial ecosystems in terms of physical conditions and their responses to biotic communities. Therefore, the terrestrial ecosystems are further divided into sub-categories of (i) upland or mountain ecosystems, (ii) lowland ecosystems, (iii) warm desert ecosystems, and (iv) cold desert ecosystems. These subecosystems may be further divided into descending orders depending on specific purposes and objectives of studies. (B) The aquatic ecosystems are subdivided into two broad categories (i) freshwater (on continents) ecosystems, and (ii) marine ecosystems. Fresh water ecosystems (Bi) are further divided into (Bia) river ecosystems; (Bib) lake ecosystems, (Bic) pond and tank ecosystems, (Bid) marsh and bog ecosystems while (Bii) marine ecosystems are divided into (Biia) open ocean ecosystems, (Biib) coastal estuarine ecosystem, (Biiic) coral reef ecosystem, or can be alternatively divided into (Biia) ocean surface ecosystems, and (Biib) ocean bottom ecosystems.

(2) On the basis of ecoclines : Ecocline means a broad transition between two different ecosystems of mainly plant communities. Infact an ecocline represents gradient along which biotic communities mainly plant community and abiotic conditions change. The study of ecocline representing the changing conditions, across an ecosystem boundary is known as 'gradient analysis' which implies the plotting of variations of plant community in particular direction and the analysis thereof and division of world ecosystem (M.J. Bradshaw, 1979). Based on above considerations R.C. Whittaker (1970) has drawn four profile diagrams of four ecoclines on a major world scale viz. (A) from Applachians to southern Texas (USA) on the basis of increasing aridity, (B) from equatorial rainforest to desert area, on the basis of increasing aridity, (C) from ground surface to higher altitudes of the Andes on the basis of increasing altitude, and (D) from tropical rainforest to tundra on the basis of decreasing temperature. Thus on the basis of above gradient profiles and associated ecoclines the following types of ecosystems in the aforesaid four situations may be identified :

(A) From mountains with relatively more moisture to the areas of increasing aridity :

(a) mesophytic forest ecosystem, (b) oak-hickory forest ecosystem, (c) oak woodland ecosystem, (d) prairie ecosystem, (e) dry grassland ecosystem, and (d) desert ecosystem.

(B) From the areas of high moisture (equatorial areas) to the areas of lowest moisture (desert) :

(a) tropical rainforest ecosystem, (b) evergreen seasonal-deciduous forest ecosystem, (c) thorn forest ecosystem, and (a) desert scrub ecosystem.

(C) from lower to higher altitudes (in the Andean area of S. America) :

(a) tropical rainforst ecosystem, (b) lower montane rainforest ecosystem, (c) montane rainforest ecosystem, (d) montane thicket ecosystem, (e) elfine woodland ecosystem, and (f) paramos ecosystem.

(D) From equatorial hot and moist areas to cold tundra :

(a) Tropical forest ecosystem, (b)sub-tropical forest ecosystem, (c) temperate deciduous forest ecosystem, (d) temperate mixed forest ecosystem, (e) boreal forest ecosystem, and (f) tundra ecosystem.

(3) On the basis of spatial scales ecosystems are divided into different types of various orders on the basis of spatial dimensions required for specific purposes. The largest ecosystem is the whole biosphere which is subdivided into two major types: (A) continental ecosystem, and (B) oceanic or marine ecosystems. The spatial scales may be brought down from a continent to a single biotic life (plant or animal).

(4) On the basis of uses E.P. Odum (1959) has divided the world ecosystems on the basis of use of harvest methods and net primary production into two broad categories viz. (A) cultivated ecosystems, and (B) non-cultivated or natural ecosystems. Cultivated ecosystems may be further subdivided into several categories on the basis of cultivation of dominant crops. e.g. wheat field ecosystem, rice field ecosystem, sugarcane field ecosystem, fodder field ecosystem etc. Similarly, non-cultivated ecosystems can be subdivided into forest ecosystem, tall grass ecosystem, short grass ecosystem, desert ecosystem, seeweeds ecosystem etc.

(5) On the basis of source and level of energy : ecosystems can be classified on the basis of source, type and amount of energy available in the ecosystem on the basic premise that the main driving force of the ecosystems for their functioning is energy. E.P. Odum (1975) has classified the ecosystems into four categories on this basis.

(A) **Unsubsidized natural solar-powered ecosystems** are those which are driven by solar energy only wherein incoming solar radiation is used to fix chemical energy. Open oceans, upland forest, wide and deep lakes may be cited typical examples of such ecosystems. The annual energy flow ranges between 1000-10,000 Kcal/m^2/yr (kilocalories per square meter per year) whereas estimated average energy is about 2000 Kcal/m^2/yr.

(b) **Natural-subsidized solar-powered ecosystems** represent tidal estuaries, lowland forests, coral reefs etc. Natural processes like tides, waves, surface runoff, wind etc. supplement solar energy input because these processes bring additional organic matter and bio-geochemical cycles help in recycling of nutrients in the aforesaid ecosystems and thus solar energy is augmented to produce organic matter through primary producers (phtotroph and chemotroph plants) so much so that these ecosystems become the most productive natural ecosystems. The annual energy flow in such ecosystems ranges between 10,000-50,000 Kcal/m^2/year and average estimated energy flow is 20,00 Kcal/m^2/year.

(C) **Man-subsidized solar powered ecosystems** are those where additional energy is supplemented by human activities (e.g. farming). In other words, man applies additional energy in the form of fertilizers both natural and chemical, machines, irrigational water etc. to make the land more productive. Thus he produces more food and fiber crops (food and fibre producing ecosystems) in a simple farming system. In a highly mechanised farming ecosystems, man increases the productivity through the use of chemical fertilizers, pesticides and herbicides (fossil energy to provide additional energy to crops, to kill insects and unwanted plants so that maximum energy is utilized by field crops), irrigational water (which augments the cycling and recycling of nutrients so that these are made available to desired plants), and by developing new hybrid high yielding varieties of seeds so that the plants remain dwarf and require relatively low amount of solar energy and can make maximum use of solar energy to prepare food through photosynthesis and thus can yield more production. The use of machines like tractors, hoes etc. also helps in augmenting the natural processes of bio-geochemical cycles (these agricultural implements make the soil horizons very friable after ploughing and thus organic matter is easily distributed in the soils for easy uptake by plants). The examples of such ecosystems are simple crop and fibre farming systems and highly advanced mechanised farming systems (agriculture) and some forms of aquaculture (fish farming, shellfish cultivation etc.). The annual energy flow is from 10,000 to 50,000 Kcl/m^2/year and estimated average annual quantity being 20,000 Kcl/m^2/year.

(D) **Fuel-powered ecosystems are represented** by urban and industrial areas where fuel energy fully replaces solar energy. The fuel energy is derived through fossil fuels like coal and petroleum which are obtained from underground quite away from the centres of utilization. Besides, energy is also supplied through hydroelectricity, nuclear power and wood coal. These ecosystems are basically wealth generating systems. These ecosystems also generate pollutants and thus are potential sources of environmental pollution in cities and towns, suburban areas, industrial areas as well as the rural atmospheric environment of even very distant places. These fuel-powered urban-industrial ecosystems though generate material wealth of the economy of the society but these depend for life support (oxygen supply and food supply) fully on solar-powered natural ecosystems, nature-subsidized solar-powered ecosystem and man-subsidized solar-powered ecosystems. The annual flow of energy ranges between 100,000 to 3,000,000 Kcal/m^2/year, the estimated average being 2,00,0000 Kcal/m^2/year. Thus these ecosystems are powered by largest amount of energy which comes from non-solar sources.

(6) On the basis of stages of ecosystem development : On the basis of characteristics of different stages of ecological successions and ecosystem development in terms of community energetics, community structure, life history, nutrient cycling and overall homeostasis (as mentioned by E.P. Odum in his paper 'The Strategy of Ecosystem Development,' 1969) the following four major types of ecosystems are identified :

(A) **Early succession ecosystems** are those which are characterised by high net community production, low biomass supported/unit energy ratio, linear food chain (plants→grazing animals→carnivores), small total organic matter, extra biotic inorganic nutrients, low biotic diversity, short size of organism, simple life cycles, rapid rate of nutrient exchange, unimportant role of detritus in the regeneration of nutrients, undeveloped mutual relationship among community species, poor nutrient conservation, high entropy (disordered biotic community) etc.

(B) **Mature ecoystem** are those which are characterised by low net community production, complex weblike food chain (besides major plants and animals, decomposers also play important roles), large total organic matter, intrabiotic inorganic nutrients, high community diversity, large size of organisms, long and complex life cycles, closed mineral cycles, important roles played by detritus in the regeneration of nutrients, quality production, developed mutual relationships among the community species, good conservation of nutrients, low entropy (ordered structure of communities) etc.

(C) **Mixed ecosystems** represent the overlapping characteristics of early succession ecosystems and mature ecosystems consequent upon general environmental change.

(D) **Inert ecosystems** represent the destroyed ecosystems. These may result from the destruction of either early succession ecosystems or mature ecosystems due to volcanic eruptions or onset of ice ages resulting into complete destruction of life.

(7) On the basis of stability or instability : The concept of stability or instability of ecosystems has been elaborated in different but contrasting ways by various scientists. In a very general sense the stability of an ecosystem is defined in terms of relationships between input and output of matter and energy and functioning of bio-geochemical cycles. An ecosystem in homeostatic or dynamic equilibrium state is that which represents (i) balance in the input and output of energy, (ii) excess of resource pool in comparison to the matter being cycled, (iii) functioning of soils, micro-climate and bio-geochemical cycle as buffers against sudden changes in external conditions, and (iv) minimization of instability due to diversity within the ecosystem. Based on this premise, ecosystems may be classified into (i) simple stable ecosystems, and (ii) complex unstable ecosystems. But this classification is highly controvercial and debatable because there are lot of variations in opinions regarding the concept of system stability. For example, if the stability is defined by frequency of fluctuation of species population, stability has been reported to increase with succession whereas if the stability of an ecosystem is defined in terms of time to be taken for a community to return to its former condition, stability may actually decrease through time (C.M. Harrison, 1980).

5.3 COMPONENTS OF ECOSYSTEM

There are three major components of ecosystems : energy component, abiotic or physical component and biotic component. The abiotic component comprises land and soils, water, air and sunlight. Besides, some organic substances (carbohydrates, protein, fat and liquid substances) and biogenic substances (carbon, nitrogen, hydrogen, phosphorous, calcium and potassium in large quantity and iron, manganese, magnesium, zinc, cobalt in small quantity) are required to sustain life of different biotic communities. Components of the ecosystems have been discussed in detail in the next chapter (Chapter 6).

The biotic components represent plants, animals and micro-organisms. Biotic components are classified into two broad categories on the basis of functions : (i) **autotrophic component** comprises those plants which produce their food themselves through photosynthesis and chemosynthesis. Thus they become (a) **photographs** (which prepare food through photosynthesis by using solar radiation) and (b) **chemotrophs** (which prepare food through chemosynthesis from inorganic substances by oxidation). Autotrophs are the primary producers of the ecosystem. (ii) **Heterotrophic components** comprise those organisms which depend on autotrophs or primary producers (plants). Besides, some heterotrophic organisms decompose and rearrange the organic substances. On the basis of feeding or getting food heterotrophs are divided into 3 sub-types : (a) **saprophytes** (depending on organic compounds in solutions derived from dead plants and animals), (b) **parasites** (depending on living organisms), and (c) **holozonic** (get food through their mouths, example-large animals including man). The elements of ecosystem are divided into 4 categories on the basis of functions : (i) abiotic elements include abiotic and dead biotic compounds of any site or habitat, (ii) producers (green plants (autotrophs) which act as intermediataries between biotic and abiotic kingdoms), (iii) consumers are primarily animals including man and they obtain their food from organic substances produced by autotrophs or primary producers, and (iv) decomposers are micro-organisms which decompose dead plants and animals and organic substances. During this process they receive their food as well as they rearrange organic substances so that these become easily available to primary producers.

5.4 FUNCTIONING OF ECOSYSTEM

The functioning of an ecosystem depends on the pattern of energy flow because all aspects of living components of an ecosystem depend on energy flow which also helps in the distribution and circulation of organic and inorganic matter within the ecosystem. While the energy flow follows unidirectional path, the circulation of matter follows cyclic paths. These aspects of energy flow and circulations of matter will be discussed in detail in the 8th and 9th chapters respectively. Here, only a brief discussion is presented so as to have a general idea of the functioning of ecosystem.

The energy pattern and flow are governed by first and second laws of thermodynamics. **The first law** states that in any system of constant mass, energy is neither created nor destroyed but it can be transformed from one type to another type (example, electrical energy can be converted into mechanical energy). In terms of ecosystem energy inflow or energy input into the system will be balanced by energy outflow from the system. **The second law** of thermodynamics states that when work is done, energy is dissipated and the work is done when one form of energy is transformed into another form. In the context of ecosystem there is dissipation of energy from each transfer point (trophic level) and thus the dissipated or lost energy is not again available to the ecosystem.

Solar radiation is the basic input of energy entering the ecosystem. The radiant solar energy is received by the green plants. Most of the received solar energy is converted into heat energy and is lost from the ecosystem to the atmosphere through plant communities. Only a small proportion of radiant solar energy is used by plants to make food through the process of photosynthesis. Thus green plants transform a part of solar energy into food energy or chemical energy which is used by the green plants to develop their tissues and thus is stored in the primary producers or autographs at the bottom of trophic levels. The chemical energy stored at trophic level one becomes the source of energy to the herbivorous animals at trophic level two of the food chain. Some portion of energy is lost from trophic level one through respiration and some portion is transferred to plant-eating animals (herbivores) at trophic level two. The transfer of energy from trophic level one (green plants) to trophic level two (herbivores) is performed through the intake of organic tissues (which contain potential chemical energy) of green plants by the herebivores. Thus the chemical energy consumed by herbivores helps in the building of their own tissues and is stored at trophic level two and becomes the source of energy for carnivores at trophic level three. A substantial portion of chemical energy is released by carnivores at trophic level three through respiration because more energy is required for the work to be done by carnivores at trophic level three (building of tissues, growing, movement for grazing, catching prey, reproduction of their offsprings etc.). Some portion of potential chemical energy is transferred from trophic level three to trophic level four or top trophic level represented by omnivores (those animals which eat both plants and animals, man is the most important example of omnivores). The animals at trophic level four mainly man also take energy from trophic levels one and two. Again some portion of energy is released by omnivores through respiration. The remaining stored chemical energy in the plants and animals is transferred to decomposers when they (plants and animals) become dead. The decomposers release substantial amount of energy through respiration to the atmosphere. It may be pointed out that at each trophic level the available potential chemical energy to be transferred to the next higher trophic level decreases as more energy is released through respiration to the atmosphere from each trophic level. Respiration means chemical breakdown of food in the body and thus respiration releases heat which is transferred to the atmosphere.

Based on above statement it may be summarised that apart from the energy released to the atmosphere through respiration, the remaining energy 'is transferred in successive consumer stages known as trophic (literally nourishment) levels from autotrophs to heterotrops (meaning that they derive their nourishment from others). Ultimately all the energy is passed on the detrivores, or decomposer organisms' (P.A. Furley and W.W. Newey, 1983).

The circulation of elements or matter or nutrients (organic and inorganic both) is made possible through energy flow. In other words, energy flow is the main driving force of nutrient circulation in the various biotic components of the ecosystem. The organic and inorganic substances are moved reversibly in the biosphere, atmosphere, hydrosphere and lithosphere through various closed system of cycles in such a way that total mass of these substances remains almost the same and are always available to biotic communities. 'In other words, the materials that make up the biosphere are distributed and redistributed by means of an infinite series of cyclic pathways motored by the continuous input of energy' (P.A. Furely and W.W. Newey, 1983). The materials or nutrients involved in the circulation within an ecosystem are grouped into three categories viz. (i) **micro-elements** (which are required in large quantity by plants, e.g. oxygen, carbon and hydrogen), (ii) **minor or micro-elements** (which are required by plants in relatively large amounts, e.g. nitrogen, phosphorous, potassium, calcium, magnesium and sulphur) and (iii) **trace elements** (plants require very small amounts of about 100 elements, important being iron, zinc, manganese and cobalt). Besides these inorganic chemical elements, there are organic materials as well which comprise (i) decomposed parts of either alive or dead plants and animals, and (ii) waste materials released by animals. A few of the chemical elements act as organic catalysts or enzymes because they help chemical reactions but seldom undergo chemical change themselves. Such chemical elements are hydrogen, oxygen and nitrogen which belong to gaseous phase (that is they are found in the atmosphere in gaseous state—atmospheric reservoir or pool) and phosphate, calcium or sulphur which belong to sedimentary phase (that is they are found in weathered rocks and soils-sedimentary reservoirs or pool).

Thus these elements, derived from atmospheric and sedimentary reservoirs, are pooled into soils from where these are taken by plants in solution form through the process of root osmosis. The plants then convert these elements into such forms which are easily used in the development of plant tissues and plant growth by biochemical processes (generally photosynthesis). Thus the nutrients driven by energy flow pass into various components of biotic communities through the process known as **'biogeochemical cycles'**. In a generalised form the biogeochemical cycles include the uptake of nutrients or inorganic elements by the plants through their roots in solution from the soils where these inorganic elements, derived from sedimentary phase, are stored. The nutrients are transported to various trophic levels through energy flow. Here the nutrients become organic matter and are stored in the biotic reservoirs of organic phase.

The organic elements of plants and animals are released in a variety of ways i.e. (i) decomposition of leaf falls from the plants, dead plants and animals by decomposers and their conversion into soluble inorganic from, (ii) burning of vegetation by lightning, accidental forest fire or deliberate action of man. The portions of organic matter on burning are released to the atmosphere and these again fall down, under the impact of precipitation, on the ground and become soluble inorganic form of element to join soil storage, while some portions in the form of ashes are decomposed by bacterial activity and join soil storage, (iii) The waste materials released by animals are decomposed by bacteria and find their way in soluble inorganic form to soil storage. Thus, biogeochemical cycles involve the movement and circulation of soluble inorganic substances (nutrients) derived from sedimentary and atmospheric phases of inorganic substances (the two basic components of inorganic phase) through biotic phase and finally their return to inorganic state. The study of biogeochemical cycles may be approached on two scales : (i) the cycling of all the elements together or (ii) cycling of individual elements e.g. carbon cycle, oxygen cycle, nitrogen cycle, phosphorous cycle, sulphur cycle etc. Besides, hydrological cycle and mineral cycles are also included in the broader biogeochemical cycles.

5.5 ECOSYSTEM PRODUCTIVITY

The productivity of ecosystem refers to the rate of growth of energy or organic matter per unit time by autotrophs at trophic level one through the process of photosynthesis with the help of solar energy. In other words, ecosystem productivity represents the total amount of energy (organic matter) fixed or stored by the autotrophs per unit time in the ecosystem. The production of organic matter or energy by autotrophos is known as **primary production** and the green plants involved in the production activity are called **primary producers.** The ecosystem productivity depends on two factors e.g. (i) the availability of the amount of solar radiation to the primary producers at trophic level one, and (ii) the efficiency of the plants to convert solar energy into chemical energy which is used by the green plants to build up their tissues. Primary production is measured in two ways : (i) **gross primary production** (GPP) is the total amount of energy produced by the autotrophs at trophic level one, and (ii) **net primary production** (NPP) represents the amount of energy or organic matter fixed or stored at trophic level one. Thus net primary production excludes the amount of energy which is lost through respiration by the autographs. Net primary production is, thus, gross primary production minus the energy lost through respiration. Net primary production represents the usable amount of energy at trophic level one, which is available to higher trophic levels. The ecosystem productivity, whether gross or net, is generally measured in gram/m^2day or year.

Biomass refers to the quantity or weight of living materials (animals, plants etc.) per unit area and is represented in terms of dry weight. Plant and animal biomass may be measured and represented separately. R.H. Wittaker and G.M. Woodwell have measured the net primary productivity and biomass of plants of the major natural ecosystems and of the whole earth's surface. Mean net primary productivity for the whole earth is 320 dry grams/m^2/year whereas the mean values for the tropical rainforest, swamps and marshes and estuaries are 2000 dry grams/m^2/year in each case. Very low net primary productivity is of extreme desert, rock and ice (3 dry grams/m^2/year), desert scrub (70 dry grams/m^2/year), open ocean (125 dry grams/m^2/year) and Tundra and Alphine ecosystem (140 dry grams/m^2/year).

Since the primary productivity of a natural ecosystem largely depends on the amount of solar radiation, there is positive correlation between primary productivity and solar radiation. Since there is marked decrease in solar radiation received at the earth's surface from equator towards the poles, primary productivity also, on an average (besides a few intermediate zones of exception), decreases markedly towards the poles. This results in spatial variations in primary productivity at regional and local scales. At a very large scale the primary productivity of the terrestrial ecosystems is far more than the marine ecosystems. E.P. Odum (1959) has identified **three levels of productivity** at world scale as follows :

(i) the regions of high ecological productivity represented by shallow water areas, moist forest (tropical and temperate), alluvial plains and regions of intensive farming;

(ii) the regions of low ecological productivity represented by arctic snow-covered wastelands, deserts and deep ocean areas, and

(iii) regions of intermediate ecological productivity e.g. grasslands, shallow lakes and farmlands except intensively cultivated areas.

See chapter 8 for detailed discussion on trophic levels and food chains.

5.6 STABILITY OF ECOSYSTEM

The stability of ecosystem refers to the balance between production and consumption of each element in the ecosystem. In other words, ecosystem stability means balance between input and output of energy and normal functioning of different biogeochemical cycles and stable condition of concentration of all elements. T.D. Brock (1967) has defined steady-state condition in mature ecosystem as 'a time-independent condition in which production and consumption of each element in the system are exactly balanced, the concentration of all elements within the system remaining constant, even though there is continual change' (Brock, 1967).

Ecosystem or ecological stability is viewed in different ways as follows :

1. No-Oscillation stability : Stability is viewed as constancy of species numbers within a natural ecosystem or the constancy of individual numbers of a species within a population. Such stability has been termed by M.I. Dunbar (1973) as 'no-oscillation stability'.

2. Stability resilience : stability of a natural ecosystem is viewed in terms of system's capacity to withstand changes brought in the system by external factors and to maintain or return to its original state after external change. Such stability has been termed by H.A. Regier and E.B. Cowell (1972) as 'stability resistance'.

3. Resilience stability : Stability has been interpreted by A.R. Hill (1975) as a resilience of system to adjust to stresses brought in the ecosystem. This is called as **'resilience stability'.**

4. Elastic stability : Elastic stability refers to the establishment of stability in a natural ecosystem after large-scale disturbances or perturbations.

5. Cyclic-stability : Cyclical stability refers to the adjustment of a system to regular external changes. There is no unprecedented disturbance or perturbation.

The natural, 'normal' or 'uneventful' ecosystem attains its steady state or equilibrium condition through **homeostatic mechanisms.** There is inbuilt self-regulating mecmanism in a natural ecosystem through which any change in the ecosystem is counterbalanced by rsponses of the system to the change and ultimately ecosystem or ecological stability is restored. For example, if there is sudden change in the ecosystem (due to any external factor) like rapid increase or decrease in the population of a species and if this change is regulated and the population returns to its normal position through self regulating mechanisms within the system and the system returns to stability, these self regulating mechanisms are called as homeostatic mechanisms. This may be further explained with an example. If the population of insects in a specific area increases significantly beyond optimum level due to favourable climate, the food supply falls short of the demand of increased insect population. With the result there is competition among the insects for food and many insects die of starvation and thus the insect population is brought back to its original size and stability is restored.

Diversity/ Stability Theory

The 'diversity/stability theory' of ecosystem or ecological stability states that ecosystem diversity and complexity enhance the stability of population in a given system. This has been illustrated in a variety of ways by different scientists e.g. (i) according to C.S. Elton (1958) increase in the diversity of food webs promotes ecosystem stability because increased food web diversity increases the resilience of the system to outside invasions of exotic organisms and reduces the fluctuation in the population within a given ecosystem. (ii) Following R.H. MacArthur (1955) the ecosystem stability increases with increase of number of links in the food web because a large number of interacting feeding links provide alternative channels for energy flow and thus is generated a wide variety of adjustments of the population to environmental changes and stresses within the ecosystem. (iii) E.P. Odum has related high species diversity of a mature ecosystem representing a 'climax community' to more stability of a natural ecosystem because as the community succession operates, the homeostasis increases due to more protection available to the members of the community against external environmental change.

Equilibrium-Non-Equilibrium Theory

There are two models of the nature of ecosystem equilibrium. The **equilibrium model** states that an ecosystem always tends towards stability. Whenever the community of an ecosystem is disturbed due to external environmental change, it quickly returns to original state whereas the **non-equilibrium model** states that ecosystem stability is rarely attained because disturbances caused by frequent external environmental change do not allow to develop ordered state of species assemblages in an ecosystem.

5.7 ECOSYSTEM INSTABILITY

Ecosystem instability refers to that state when an ecosystem is unable to adjust with environmental changes. This so happens when the changes are continuous and enormous and these changes exceed the resilience or capacity of the ecosystem. For example, rapid rate of mass felling of trees in a forest ecosystem seldom allows regeneration of forest community because exposed surface due to deforestation is subjected to intense weathering and erosion and nutrients are washed out by surface runoff. Himalayan forest ecosystem is a typical example of ecosystem instability because mass deforestation and subsequent grazing have resulted into complete removal of forests at certain localities.

The factors responsible for ecosystem stability or instability should always be viewed in terms of ecosystem resilience. If the environmental changes exceed the ecosystem resilience, ecosystem instability is caused but when the ecosystem resilience is such that it can withstand the environmental changes, ecosystem stability is maintained. The environmental changes which are responsible for ecosystem instability are both natural ones (climatic change, for example) or man-induced.

Man causes instability in the natural ecosystem by :

- destroying completely or partly the natural vegetation or original animal species or by replacing them by other vegetation or animal species;
- introducing exotic plants or animals or both to any area where such biotic communities were not present previously;
- altering or modifying one or more components of physical environment (such as land use changes);
- introducing foreign chemical substances through the use of chemical fertilizers, pesticides and herbicides;
- increasing or decreasing the original proportion of atmospheric gas i.e. by changing the atmospheric chemistry e.g. emission of greenhouse gases and ozone depletion;
- manipulation of environmental processes etc.

Man has modified many of the natural ecosystems and hence has disturbed the stability of ecosystem and ecological balance through fast rate of urbanization and industrialization, mechanization of agriculture, alarming rate of deforestation etc. Most of the forest ecosystems right from the rainforests of Amazonia to mountain forests in all the climatic regions have been degraded due to reckless felling of trees. The freshwater terrestrial ecosystems such as rivers and lakes have been greatly polluted due to immense volume of sewage water, coming from the urbaan and industrial sectors, discharged into rivers and lakes. Managed ecosystems such as farmlands have been destabilized due to heavy irrigation and excessive use of chemical fartilizaers and herbicides. The temperate grassland ecosystems (such as Steppes, Praries, Pampas etc.) have been entirely changed by removing natural grasses and other vegetation and have been changed into farmlands. Many more examples may be cited to demonstrate the impacts of human activities on stability/instability of ecosystems. (see chapter 3 and 15 for further reading materials on this theme).

6

BIOSPHERE AS AN ECOSYSTEM

6.1 SYSTEM

'A system may be defined as a set of objects that are considered together by studying their relationships to each other and their individual attributes' C.A.M. King, 1966. R.J. Chorley and B.A. Kenneday (1971) have defined system as 'a structured set of objects and/or attributes. These consist of components or variables that exhibit discernible relationships with one another, and operate together as a complex whole according to some observed pattern'. Systems are generally classified into three types viz. (i) **Isolated systems** are those in which the boundaries for input of energy and output or export of mass and matter are closed or fixed, (ii) **Closed systems** are those whose boundaries are fixed and mass and matter cannot cross the system boundary i.e. after the initial input of matter no further matter can enter the system but there is no binding for the renewed import and export (input and output) of energy into and out of the system respectively, and (iii) **Open systems** are those systems wherein there is continuous input and output of mass (matter) and energy. Thus the open systems function in such a way that there is balance between input and output of matter and energy and the systems always tend to be in a steady state of balance.

6.2 THE BIOSPHERE

The biosphere is a life supporting layer which surrounds the earth and makes plant and animal life possible without any protective device. The 'organic world or biosphere is that part of the earth which contains living organisms-the biologically inhabited soil, air and water' (J. Tivey, 1982). The biosphere consists of all the living organisms (the biotic component), energy (the energy component) and physical environment (the abiotic component) and there are continuous interactions between living organisms and physical environment and among the living organisms themselves. The average thickness of the biosphere or life supporting layer consisting of air, water, soil and rock is about 30 km. The upper limit of the biosphere is determined by the availability of oxygen, moisture, temperature and air pressure. Decrease in oxygen, moisture, temperature and air pressure with increase in height in the atmosphere limits the upper boundary of the biosphere. Though the NASA has discovered the presence of bacteria upto the height of 15km in the atmosphere but the lower layer of the atmosphere upto a few hundred meters accounts for most of the living organisms because favourable environmental conditions are available for the growth and development of living organisms in the lower part of the atmosphere. The lower limits of the biosphere are determined by the availability of required amount of oxygen and light which can sustain life. Thus, the depth of the biosphere over the land is upto the depth of the deepest roots of the trees or the depth upto which can live the burrowing organisms or the depth at which lie the parent bed-rocks. The biosphere extends upto greater depth in the oceans. The existence of life has been detected upto a depth of 9,000 m in the deep oceanic trenches and deep sea plains (fig. 6.1).

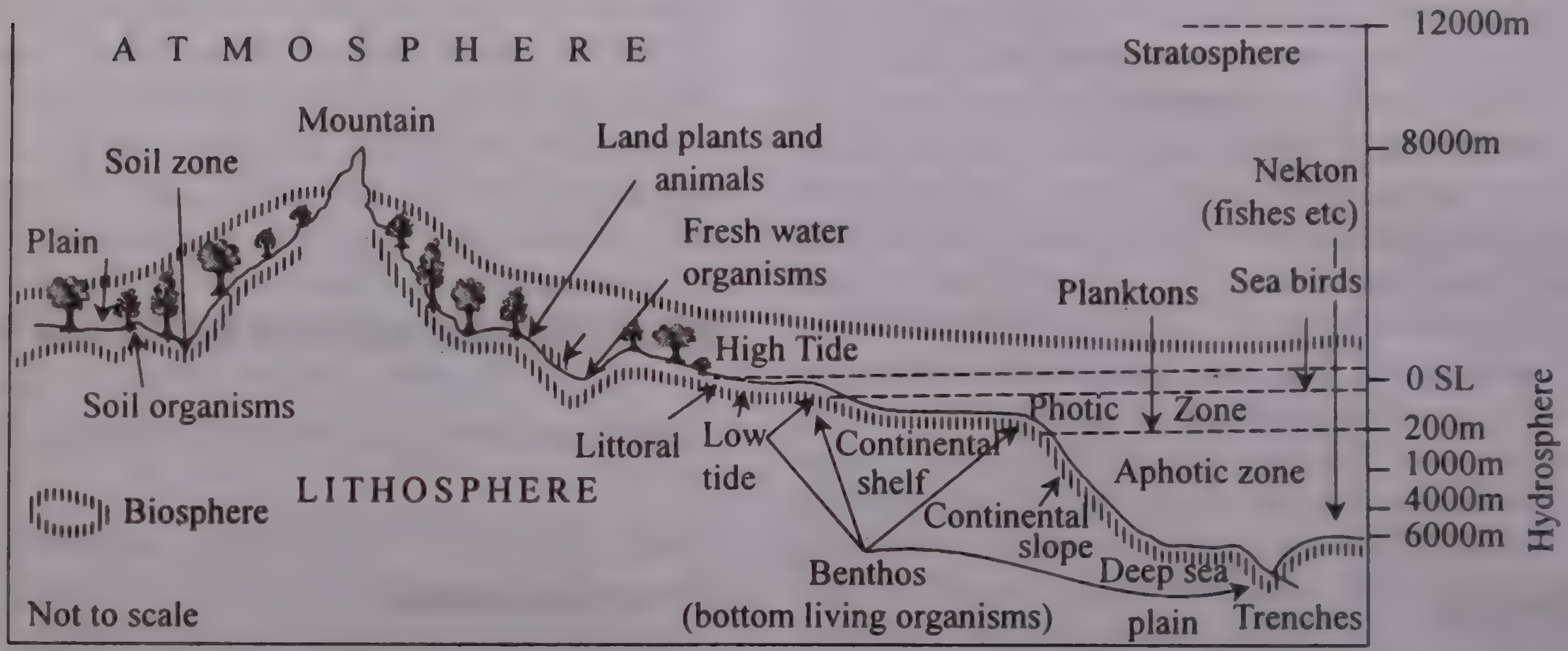

ATMOSPHERE
Stratosphere
12000m
8000m
Mountain
Soil zone
Land plants and animals
Plain
Fresh water organisms
Nekton (fishes etc)
Sea birds
Planktons
High Tide
0 SL
Photic Zone
200m
Soil organisms
Littoral
Low tide
Continental shelf
Aphotic zone
1000m
4000m
6000m
Hydrosphere
LITHOSPHERE
Biosphere
Continental slope
Deep sea plain
Trenches
Benthos (bottom living organisms)
Not to scale

Fig. 6.1 : Extent of biospehre (life supporting layer).

6.3 BIOSPHERE AS A SYSTEM

The biosphere is an example of a system as it is composed of basicaly three components viz. (i) organic component (plants, animals including man and micro-organisms), (ii) inorganic or abiotic component (physical environments-land, soils, air, water), and (iii) energy component (solar and geothermal energy) and these three components are mutually interdependent and are interrelated through a series of large-scale cyclic mechanisms which make the input-output mechanism effective in the biopshere. The biosphere is considered as an open system because there is continuous flow of energy and output of matter. As long as the balance is maintained between the input of energy and mater and output of matter, the biospheric system remains in equilibrium condition but when this critical balance is disturbed, the equilibrium state of the biospheric system is also disturbed and several environmental and ecological problems crop up. It may be pointed out that the equilibrium state of the biospheric system which is, in natural state, self-sustaining and ecologically efficient, depends on the intimate relationships between various components of the biosphere and a series of large-scale cyclic mechanisms (energy cycle, hydrological cycle, sediment cycle, nutrient cycle etc.-collectively known as biogeochemical cycle) as these cycles influence the biotic, abiotic and energy components of the biosphere whereas in turn these components also influence the cyclic mechanisms involving the movement and transfer of energy, water, sediments and nutrients throughout the biospheric system. If any of the attributes of the biospheric system crosses the critical limit the system equilibrium is disturbed.

6.4 BIOSPHERE AS AN ECOSYSTEM

Ecosystem has been defined and its various aspects have been described in detail in the preceding chapter (chapter 5). Since ecosystem is a fundamental functional unit occupying spatial dimension on the earth and is characterized by total assemblage of biotic community and abiotic components together with energy component and their (of various components-biotic, abiotic and energy) mutual interactions within a given time-unit, the biosphere becomes the largest ecosystem because it (the biospheric ecosystem) consists of biotic component (plants, animals including man and microorganisms), abiotic component (land, air, soils and water) and energy component (solar and geothermal energy) and the biotic and abiotic componts are intimately interrelated through a series of large-scale cyclic mechanisms, collectively called as biogeochemical cycle.

6.5 SUB-SYSTEMS OF BIOSPHERE

The biosphere consits of two major systems viz. (i) terrestrial biomes systems, and (ii) aquatic biomes systems. The terrestrial biomes systems are further comprised of three subsystems viz. (i) plant systems, (ii) animal system, and (iii) soil system. These subsystems are intimately interrelated among themselves through the cyclic pathways of movements and transfer of energy and materials (fig. 6.2) whereas the aquatic biomes systems are also composed of three sub-systems viz. (i) plant system, (ii) animal system and (iii) nutrients system. These three sub-systems, of aquatic biomes system of the biosphere are also intimately interrelated through cyclic pathways of movements of energy and matter among themselves.

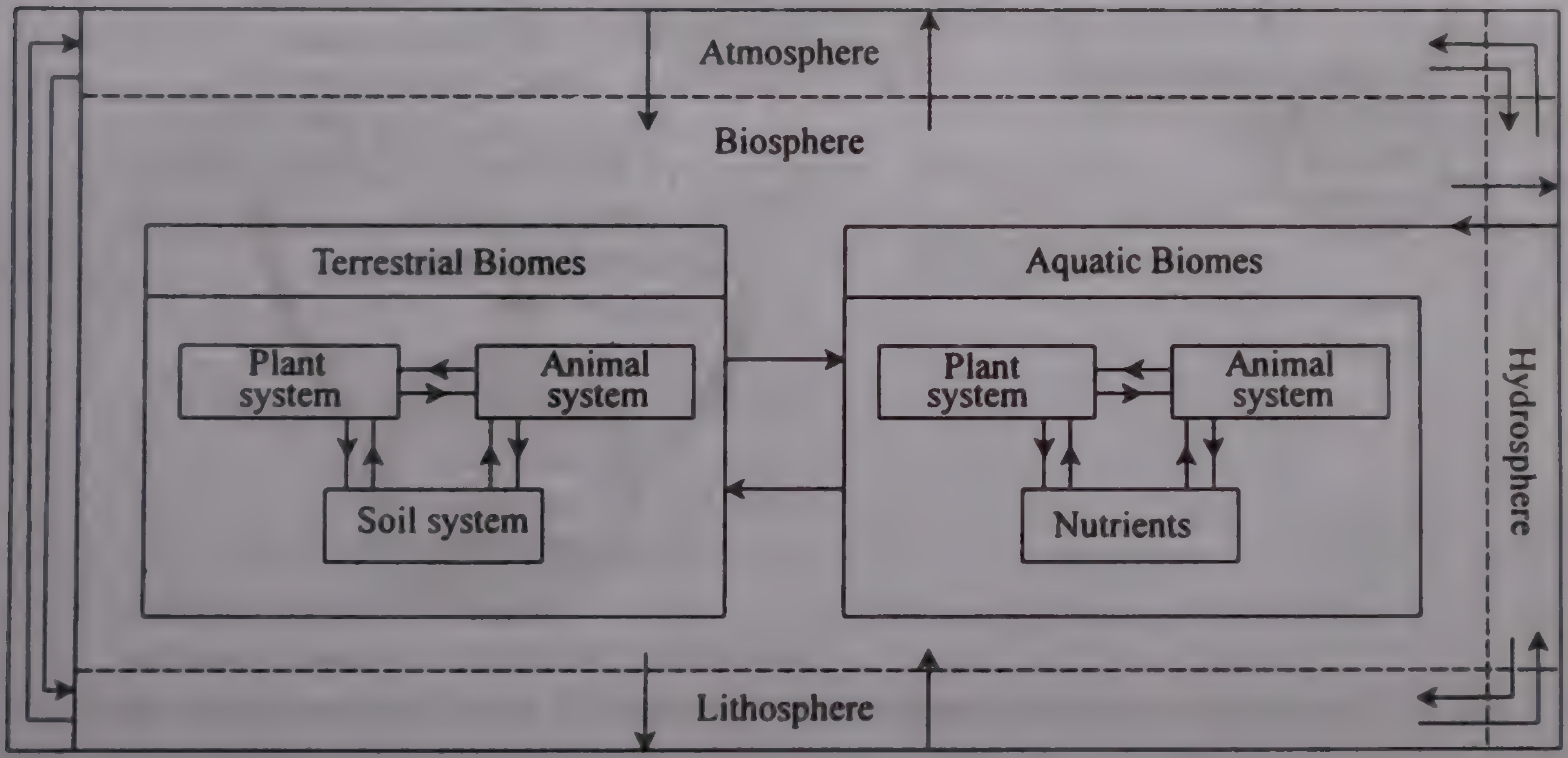


Fig. 6.2 : Subsystems and components of biosphere and their interrelationships. Arrows indicate pathways.

Modifiers of Biosphere

The biospheric ecosystm is affected and modified by certain factors either directly or indirectly. These factors are called as modifiers of ecosystems. The factors or modifiers which directly or indirectly affect ecosystems are of three categories, e.g. (i) physical modifiers, (ii) chemical modifiers, and (iii) biological modifiers (fig. 6.3). The physical factors affect physical properties of the atmosphere which in turn affect climate and climate ultimately affects the ecosystems. Physical modifiers also affect ecosystems through temperature changes, water flow, fire, excavation (mining), constructional works etc. The chemical factors affect the composition of the atmosphere which in turn affects climate which ultimately affects the ecosystems. Water and soil composition is highly modified by chemical elements and thus modified soil and water affect the ecosystems. The biological factors like cropping patterns, population characteristics, manipulation of species density, and distribution and species genetics also affect the ecosystems.

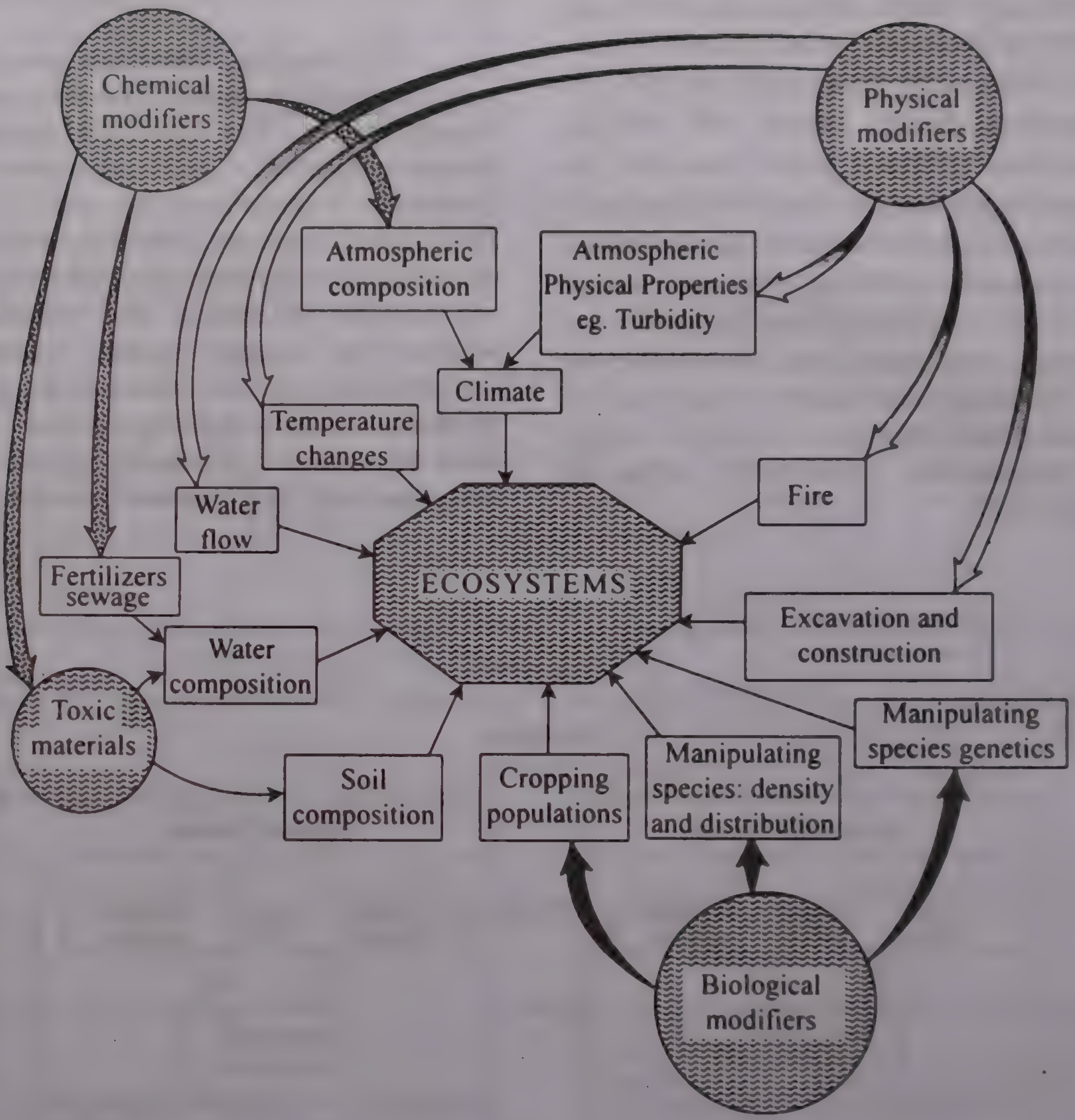

Chemical modifiers
Physical modifiers
Atmospheric composition
Atmospheric Physical Properties eg. Turbidity
Climate
Temperature changes
Water flow
Fire
Fertilizers sewage
ECOSYSTEMS
Excavation and construction
Water composition
Toxic materials
Manipulating species genetics
Soil composition
Cropping populations
Manipulating species: density and distribution
Biological modifiers

Fig. 6.3 : Factors which affect the bioshpere directly or indirecly (after Furley and Newey, 1983).

6.6 COMPONENTS OF BIOSPHERE, ECOSYSTEM AND ENVIRONMENT

If we consider the whole of the biosphere as an ecosystem at global scale, the components of the biosphere and the biospheric ecosystem become the same. The total physical environment at global scale also contains the same components as those of the biosphere and the ecosystem (biospheric ecosystem). The biosphere, the ecosystem and the environment consist of three components viz. (i) inorganic or abiotic or physical component, (ii) energy component and (iii) biotic or organic component. It may be pointed out that energy component may also be considered with abiotic component.

6.6.1 ABIOTIC COMPONENTS

The abiotic (or inorganic or physical component) of the biosphere or the ecosystem represents physical environment of the whole biosphere or part thereof. This component, on an average, includes the lithosphere, the atmosphere and the hydrosphere. Generally, these are considered as land and or soil, air and water respectively. If the whole of the biosphere is taken to be an ecosystem at global scale, these three physical (abiotic) components are considered as the sub-systems of biospheric system (ecosystem).

1. Lithospheric Components

The lithosphere is an important component of the biosphere. The lithospheric components consist of (from smaller to bigger) elements (iron, nickel, oxygen, nitrogen, hydrogen, carbon etc.), minerals (hematite, dolomite, feldspar etc.), rocks and soils (rocks : igneous, sedimentary, metamorphic and their sub-types; soils-podzols, latosols, alluvia, loam etc.), micro-landforms (relief features of third order viz. erosional landforms-V shaped valleys, U shaped valleys, sea cliffs, rock-cut plantforms etc., depositional landforms-sand dunes, deltas, eskers, sea beaches etc.), meso-landforms (relief features of second order e.g. landforms evolved due to endogenetic forces like mountains, plains, plateaux, faults etc.) and macro-landforms (relief features of first order e.g. continents).

The lithosphere accounts for about 29 percent of the total surface area of the globe. The landforms of various sizes as mentioned above provide a variety of habitats for the plants and animals. Thus, it is necessary to study the main characteristics of lithospheric components and all the physical processes whether exogentic or endoenetic, which affect the lithosphere- the surface of the earth. The **geological cycle** involving a set of processes and sub-cycles e.g. tectonic cycle, rock cycle, geochemical cycle, water cycle etc. is responsible for creation, maintenance, changes or destruction of the materials of the earth for example-elements, minerals, rocks, soils, water and the landform assemblage.

The **tectonic processes,** collectively known as **'tectonic cycle'**, are responsible for the creation of new surface features or relief features on the earth's surface such as continents, ocean basins, mountains, plateaus, lakes, faults, scarps, rift valleys etc. The tectonic processes are driven by endogenetic forces which originate deep within the earth. These endogenetic forces, geologically known as constructive forces, create surface irregularities on the earth's surface by deforming the earth's crust.

The strong and solid outermost zone of the earth called as crust (fig. 6.4) represents the lithosphere which is not a continuous and uniform layer rather it is thicker in the continents and very thin in the ocean basins. This solid crust is called as plate which is continuously moving over the weak and partially molten asthenosphere, the outer zone of the mantle. The lithospheric parts of the crust are termed as continents which are like rafts and are constantly moving with respect to each other. Thus, the hard rigid part of the crust is called plate. There are 6 major plates (Eurasian plate, American plate, African plate, Indo-Australian plate, Antarctic Plate, and Pacific plate). All of the activities of movement of plate with respect to each other, the collision of plates, divergence of plates, the topographic expressions in the form of crustal deformations caused due to plate movements, etc. are called as plate tectonics. The evidences of sea-floor spreading and palaeomagnetism have almost validated the concept of continental drift. The thermal convective currents originating from the mantle and the upper core are considered to be the main driving force of the plates (continents).

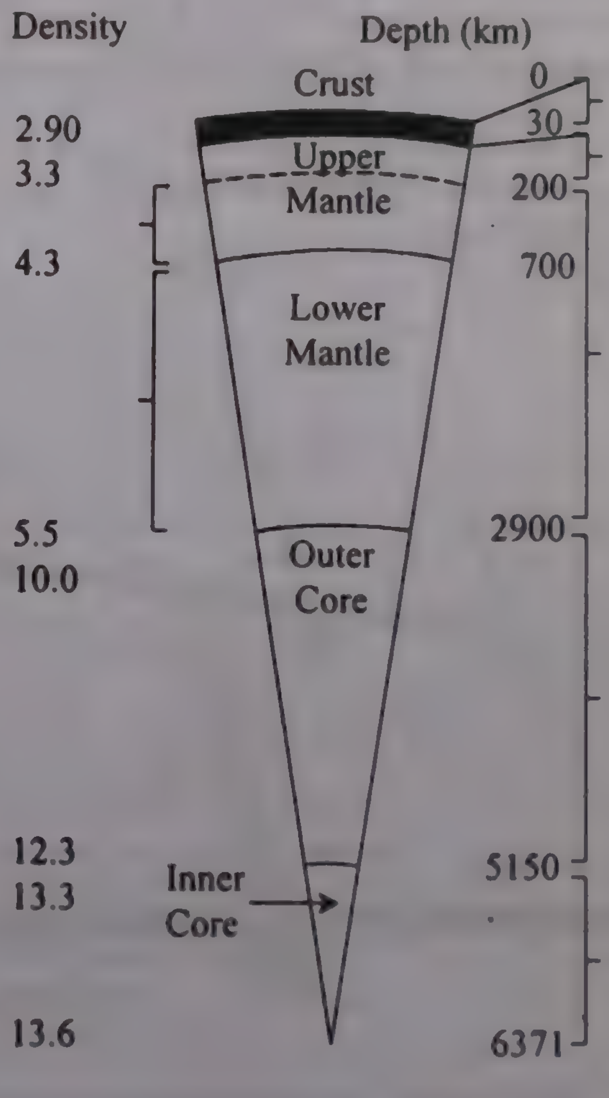


Fig. 6.4 : Interiror of the earth (based on the information of the International Union of Geodesy and Geophysics).

Geologically, the boundaries between the plates or plate margins are most important because nearly all of the tectonic activities take place along the plate margins. Thus the plate margins are considered as geologically most active areas as most of the volcanic activity, earthquakes, orogensis, faulting etc. occur along these margins. Transform faults are created along divergent (constructive) plate boundaries where two plates move in opposite directions. Convergent plate boundaries (destructive plate boundaries), where two plates converge and one plate margin having relatively less density is subducted below the other plate, are responsible for the origin of mountains. Conservative plate boundaries create transform faults and give birth to vulcanicity. It is apparent that plate movements create different types of topographic features such as faults, mountains, plateaus, volcanic cones, volcanic plateaus and plains etc. which become suitable habitas for plants and animals. On the other hand, marine earthquakes measuring 7.5 or more on Richter scale caused by divergent or convergent plate movements, give birth to furious and destructive **tsunamis** which destroy many plants and animal communities of marine ecosystems. For example, killer tsunamis of December 26, 2004 of the Indian ocean caused by deep sea powerful earthquake measuring 9.3 on Richter scale near Sumatra damaged coral reefs around Andman and Nicobar isnalds.

In fact, plate tectonics largely affect the biospheric ecosystem in general and man in particular. The continents, mountains, plateaus etc. provide solid bases and habitats for terrestrial organisms and form all terrestrial ecosystems. These crustal features are affected and modified by plate movements and therefore the nature and characteristics of terrestrial ecosystems are closely related with plate tectonics. It is significant to point out that two major natural environmental hazards e.g. volcanic eruptions and earthquakes which are threat to biotic communities in general and mankind in particular, are also associated with plate tectonics (figs. 6.5 and 6.6).

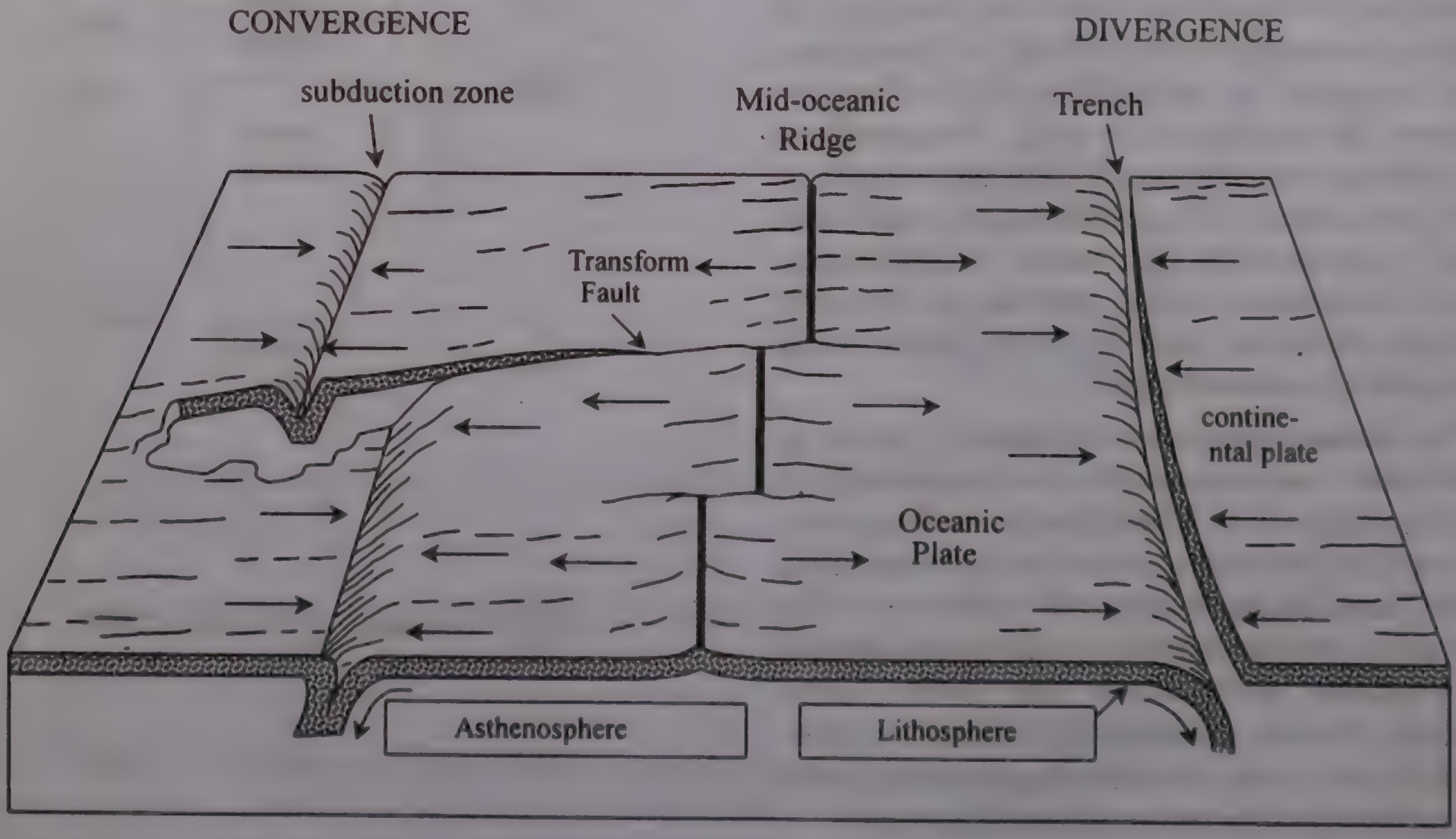


Fig. 6.5 : Salient features of plate tectonics.

The **materials** of which the crust has been composed of, are very significant for biological communities. The smallest component of the lithospheric or crustal components is element. As regards the whole earth eight most abundant elements (iron, oxygen, silicon, magnesium, nickel, sulphur, calcium, ammonium; table (6.1) constitute 99 per cent of the total mass of the earth whereas only four elements (iron, oxygen, silicon and magnesium) account for 90 per cent of the total mass of the earth.

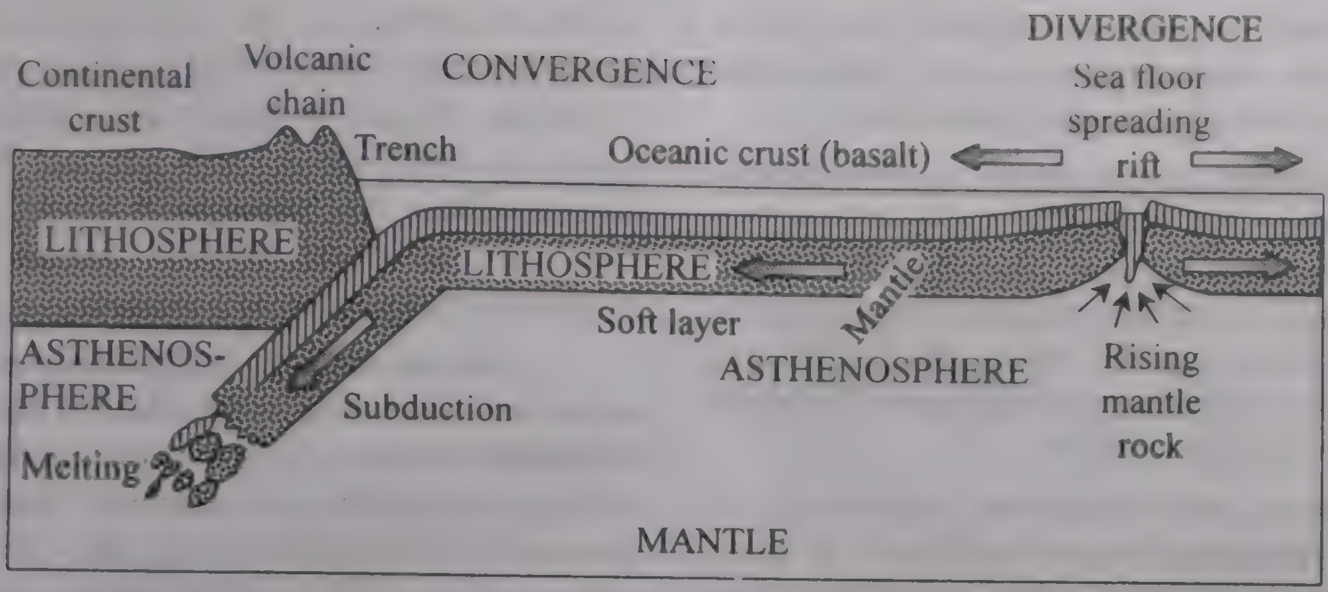


Fig. 6.6 : The illustration of subduction and divergence of plate margins.

On the other hand, the eight most abundant elements which constitute 99 per cent of the total mass of the crust are oxygen, silicon, aluminum, iron, magnesium, calcium, potassium and sodium (table 6.1).

Table 6.1 : Important elements of the whole earth and the crust

Whole Earth		Earth's Crust	
Elements	Percentage	Elements	Percentage
1. Iron	35	1. Oxygen	46
2. Oxygen	30	2. Silicon	28
3. Silicon	15	3. Aluminum	8
4. Magnesium	13	4. Iron	6
5. Nickel	2.4	5. Magnesium	4
6. Sulphur	1.9	6. Calcium	2.4
7. Calcium	1.1	7. Potassium	2.3
8. Aluminum	1.1	8. Sodium	2.1
Others less than 1.0		Others	less than 1.0

More than one element of the earth's crust are organised to form compounds which are known as minerals and minerals are organised to form rocks. The study of elements and minerals as component of physical environment is very significant as the physical and chemical properties of major minerals are largely related to soil fertility, water holding capacity of soils, richness or poorness of resources of a given region, sources of pollutants etc.

The important **mineral groups** are silicates, carbonates, sulphides, metal oxides etc. (1) The **silicate minerals** are very important rock making minerals. The most outstanding rock forming silicate mineral groups are quartz, felspar and ferromangnese. Quartz is comosed of two elements viz. silicon and oxygen and is generally a hard and resistant mineral. The most abundant and the most outstanding rock-forming mineral is felspar which is very important economic mineral because it is used in ceramics and glass industry. Felspar is very weak mineral and is easily broken down and decomposed due to chemical weathering and is changed into clays as hydrated aluminosilicates. Clays are very important for life because these hold chemical elements which increase soil fertility. When silicon and oxygen combine with iron and magnesium, ferromagnesium minerals are formed. Ferromagnsium minerals are easily weathered and eroded and are easily altered and removed. The rocks having abundant ferromagnesium minerals provide weak structure for construction of buildings, roads, dams and reservoirs, tunnels etc. (2) **Carbonate group** of minerals is very much susceptible to chemical weathering and erosion in humid areas. Calcite is the most important mineral of this group. Limestones and marbles having abundant calcite are corroded by the surface and groundwater and big caves are formed below the ground surface. Such areas provide very weak structure for construction sites e.g. construction of buildings, roads, dams and reservoirs, air strips, tunnels etc. (3) **Sulphide minerals** include pyrites, iron sulphides etc. When these minerals come in contact with water or air, these form ferric hydroxides and sulphuric acids which cause serious environmental problems.

(4) **Metallic elements** like iron, aluminium etc. after reacting with the atmospheric oxygen form metal oxides which are commercially very important because these are used in several industries.

Rocks (igneous, sedimentary and metamorphic, and their types and subtypes) are weathered by different weathering processes (physical, chemical, biotic weathering) in varying climatic conditions to form different types of soils which are significant components of the biospheric components because these provide nutrients to plants.

Soil system is very important component of lithospheric components because soils act as vital transfer pathways of energy in the biospheric ecosystem and are very important for the biological cycling of nutrients. The soil system acts as a very important **'biological furnace'** between the vegetation cover and the unweathered parent rocks. Thus based on significance of soil system in the biospheric ecosystem, soils will be discussed in detail in the succeeding 7th chapter.

The study of forces affecting the earth's crust, which provides habitats of different sorts to biological communities is of prime significance in environmental geography. The endogenetic forces originating from within the earth create different types of landforms of varying dimensions such as mountains, faults, plateaus, lakes, volcanic cones, lava plateaus and plains etc. These features provide suitable habitats to various biological communities. Such topographic features having varying combinations of abiotic and biotic components become distinct ecosystems such as mountain ecosystem, plateau ecosystem, fault ecosystem etc.

The exogenetic processes originating from the atmosphere are called denudational processes including both weathering and erosion. Different erosional processes such as fluvial, glacial, aeolian, marine, periglacial processes etc. called as geomorphological processes, create different types of erosional (e.g. gorges, canyons, cirques, caves, wavecut plateforms, cliffs etc.) and depositional (such as alluvial fans and cones, alluvial plains, deltas, sand dunes, sea beaches etc.) landforms which provide suitable habitats for different biologic communities.

2. Atmospheric components

The atmosphere is a significant component of the biospheric ecosystem because it provides all the gases necessary for the sustenance of all life-forms in the biosphere. It also filters the incoming solar radiation and thus prevents the ultraviolet solar radiation waves to reach the earth's surface and hence protects the earth's surface from becoming too hot. Thus it is imperative to study the composition and structure of the atmosphere and the elements of weather and climate.

The atmosphere is a gaseous envelope which surrounds the earth from all sides and is attached to the earth's surface by gravitational force. The height of the atmosphere is estimated between 16 to 29 thousand kilometers from the sea level. It is estimated that 97% of the effective atmosphere is upto the height of 29 km. The atmosphere is composed of (i) gases, (ii) vapour, and (iii) particulates. Nitrogen (78%) and oxygen (21%) are the major gases which constitute 99% of the total gaseous composition of the atmosphere. The remaining 1 per cent is represented by carbon dioxide (0.03%), hydrogen, neon, helium, argon, xenon, ozone etc. The vapour content in the atmosphere ranges between zero to 5 per cent by volume. The atmospheric vapour is received through the evaporation of moisture and water from the water bodies, vegetation and soil covers of the lithosphere and seas and oceans. Vapour in the atmosphere decreases from the equator towards the poles and this trend of distributional pattern of atmospheric vapour affects vegetation though temperature is also significant factor which controls vegetation. The moisture content in the atmosphere is responsible for the creation of several forms of condensation and precipitation (clouds, fogs, frost, rainfall, dew, ice, hailstorm, snowfall etc.). Vapour is transparent for incoming short wave solar radiation so that solar rays reach the ground surface without much obstacles but vapour is less transparent for outgoing terrestrial long wave radiation and therefore it helps in heating the earth's surface and the lower portion of the atmosphere. The solid particles present in the atmosphere include dust particles, salt particles etc. These particulates help in the scattering of solar radiation which resutls in the appearance of blue colour of the sky, charming colour during sunrise and sunset. Salt particles become hygroscopic nuclei and thus help in the formation of drops, clouds and various forms of condensation and precipitation.

Atmospheric **gases** (mainly oxygen, nitrogen and carbon dioxide), **humidity, sunlight** and **tempera-**

ture are most significant attributes of the atmosphere which affect productivity of green plants through photosynthesis. There is positive correlation between insolation (temperature) and availability of humidity, and ecological productivity of primary producers (autotrophic green plants). On an average, temperature decreases from equator towards the poles and hence ecological productivity also decreases in the same direction. Various combinations of atmospheric humidity and precipitation have been responsible for different types of climates and climatic regions on the earth's surface (e.g. equatorial climate, savanna climate, monsoon climate, hot desert climate, mediterranean climate, taiga climate, tundra climate etc.) and these account for varying degree of ecological productivity. The equatorial rainforest climate accounts for the highest ecological productivity due to sufficient supply of sunlight and moisture throughout the year. The hot arid climate and tundra climate are characterized by lowest ecological climate because of least moisture in the former and least availability of insolation in the latter.

3. Water Components

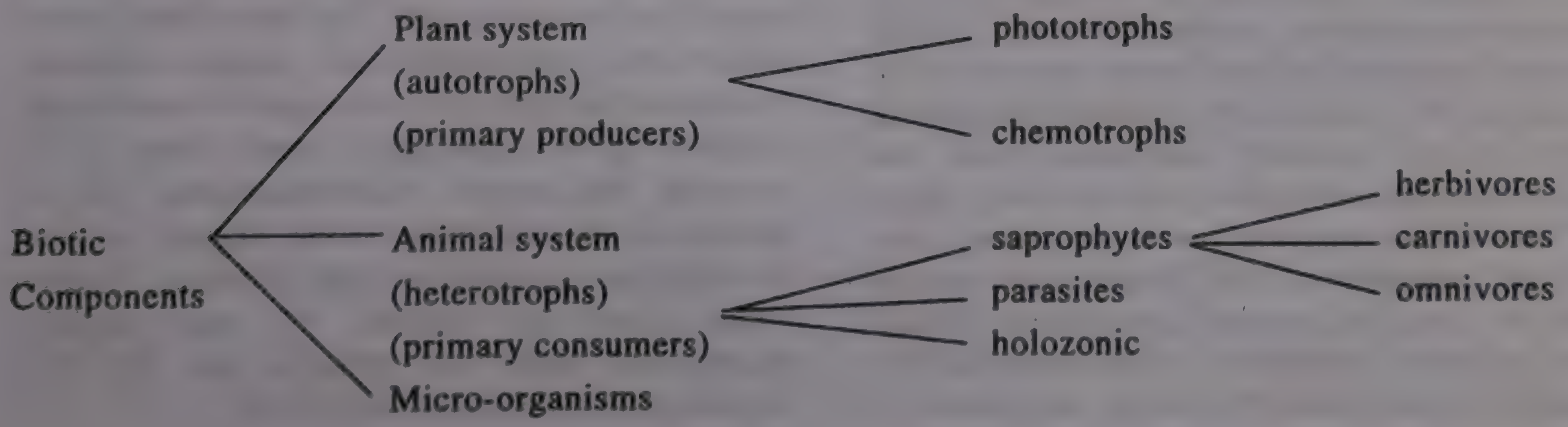
Water is very important component of the abiotic or physical components because it is very essential element for all types of life in the biosphere because without water no life is possible on this planet earth. Water plays very important role in the circulation of nutrients in the various components of the ecosystems and it makes the biogeochemical cycle effective in the biosphere. The water components consist of (i) surface water, (ii) groundwater, and (iii) oceanic water.

The main source of surface water is precipitation and melt-water. The groundwater is indirect source of surface water because some groundwater reappears on the earth's surface through springs and seepages. The surface water includes the water of lakes, ponds and rivers.

The water bodies mainly **oceanic areas** are the source areas for the water vapour which provide water solution for the biological communities in the biosphere. The hydrosphere provides not only suitable habitats to aquatic organisms but also provides life to them. The aquatic organisms are largely affected by the depth to which sunlight can penetrate. The sunlight reaches the sea water upto the depth of 200 m. This zone is called **photic zone** which maintains planktons. The zone beyond 200 m depth is called **aphotic zone** which supports nektons, whereas the sea bottoms right from the continental shelves to the oceanic trenches support **benthos** or sea bottom living organisms. Several properties of the oceans e.g. temperature, density and salinity of oceanic waters, oceanic movements (sea waves, ocean currents, tides etc.), ocean deposits and bottom reliefs affect biotic component of aquatic ecosystem (marine ecosystems).

6.6.2 BIOTIC COMPONENTS

Biotic or organic components of the biosphere/ecosystem/environment consist of three subsystems e.g. (1) **plant system**, (2) **animal system** including man, and (3) **micro-organisms**. Of these three sub-systems plants are the most important because plants alone produce organic matters which are used by themselves and by animals including micro-organisms either directly or indirectly. Plants also make the cycling and recycling of organic matter and nutrients possible in different components of the biospheric ecosystem.



1. Plant System

Social groupings of plant species are called **plant community** and plants are basic unit of this community. Plants are found on any land in different forms e.g. woodland, forest, meadows, bogs, grasslands, marshlands etc. These different forms of plants are collectively known as **vegetation.** In other words, 'all the plants which grow together in any area form its vegetation, the character of which depends not just on the different species present but on the relative proportions in which their members are represented' (Joy Tivy, 1982). Thus the vegetation of any particular habitat consists of groups of plants of different species or of the same species which are ecologically related, meaning thereby different plant groups are able to occupy the same habitat because of their competitive ability and range of tolerance. **Plant community** has been defined in a variety of ways by ecologists and biogeographers e.g. (1) Social groupings of plant species are called plant community, (2) Plant community represents groups of plants which occur together and possess a certain degree of unity of individuality, (3) Plant community is a group of plants which occupy a definite physical habitat, (4) Plant community refers to groups of plant species which have distinctive characteristics of their composition and structure in relation to their physical habitat.

There are certain characteristics of plant community e.g. (i) Plant community consists of two or more different species of plants, (ii) The plant species of plant community are capable of growing together in a particular physical habitat which they inhabit and thus different members (species) of a plant community are ecologically interrelated, (iii) A plant community has a well defined composition and structure which are attained over time through the interactions between different plant species and between plant and their physical environment, (iv) Plant community represents the ecological conditions of a region or area or physical habitat, (v) The structures, composition and growth form of different species of a given plant community reveal the effects of both mutually interacting biotic and abiotic environments on them. In other words, this is well known fact that the species of plants, their structure, composition and growth form depend upon the nature of mutual interactions between abiotic and biotic components of the environment, it is easier to understand the nature and pattern of mutual interactions of factors (components, both abiotic and biotic) which affect the species, their structure, composition and growth form. Out of the abiotic or physical factors, climate and soil mostly affect the species of plants, their structure and growth form. In turn plants also affect and control properties of soils and climatic conditions of their physical habitat. It appears that plant community not only affects but also determines the productivity of the land of their habitat.

Plants are **primary producers** because they produce their food themselves through the process of **photosyntehsis**. Thus plants are also called auotrophs. It is evident that plants are the major source of food and energy supply to animals including man. The study of **plant components** includes the consideration of (i) classification of plants, (ii) major divisions of plant kingdom, (iii) plant system, (iv) plants and their environment, (v) plant communities (including vertical structure, species composition, community development and community hierarchy), (vi) plant evolution, (vii) distribution, dispersal and extinction of plants etc. These aspects of plant system will be discussed in chapter 10.

2. Animal System

On a functional basis the biotic or organic components of biospheric ecosystem are divided into two broad divisions e.g. (i) **autotrophic component** (which represents plants. These have been briefly discussed above), and (ii) **heterotrophic component** includes those animals which depend on autotrohpic green plants (primary producers, which produce their food themselves. It may be pointed out that it is not necessary that plants always have roots, this is the reason that some bacteria also fall in the category of plants because they produce their food themselves) for their food. The main functions of heterotrophic components or animals (primary consumers) include (i) to use organic matter made available by the autotrophic green plants, (ii) to rearrange the organic matter/elements, (iii) to decompose organic elements etc. Organic matters are available to animals in three forms e.g. (i) from living plants and animals, (ii) from partially decomposed plants and animals, and (iii) from organic compounds in solution form.

Thus heterotrophic animals are classified into 3 broad categories on the basis of the availability of organic matter to them.

(A) **Saprophytes** are those animals which live on organic compounds in solution form derived from dead plants and animals.

(B) **Parasites** are those animals which depend on other living organisms for their food and life.

(C) **Holozonic** animals are those who take their food through their mouths. All the big animals like elephants, cows, camels, lions etc. are included in this category.

3. Micro-Organisms

Micro-organisms are also known as **decomposers** because these decompose the dead plants and animals and other organic matter in different forms. During the process of decomposition of organic matter micro organisms obtain their food as well as they differentiate and separate complex organic matters and thus make them simple so that these may be again used by autotrophic primary producer green plants. A large number of microbacteria and fungi are included in the category of micro-organisms.

There are three stages of the study of animals and micro-organisms e.g. (1) identification of all animals and micro-organisms in a given region, (2) classification of all identified animals and micro-organisms, and (3) the study of distributional parterns, evolution and extinction of animals. It is significant to point out that animal kingdom includes a variety of animals and micro-organisms ranging from microscopic organisms to giant whales. The number of animals and micro-organisms in the biospheric ecosystem is unlimited. Though all organisms in the biosphere could not be identified and named yet animals are classified into seven successive groups (from higher order to lower order) on the basis of available knowledge e.g. (i) animal kingdom, (ii) phyla, (iii) classes, (iv) order, (v) family, (vi) genera, and (vii) species. The distribution of animals, their evolution, dispersal, extinction, relationships between animals, and their physical environment, the roles of animals in the ecosystems, relationships between plants and animals and their mutual interactions will be discussed in the succeeding chapters (10 and 11).

The other properties of ecosystems viz. ecosystem productivity, ecosystem stability and instability etc. have already been discussed in the preceding chapter (chapter 5). Energy flow in the ecosystem (sources of energy, ecological production, trophic levels, food chains, ecological pyramids, flow of energy etc.) and circulation of elements in the ecosystem would be discussed in the 8th and 9th chapters.

7

SOIL SYSTEM

7.1 MEANING AND IMPORTANCE

Ordinarily speaking soil represents the loose and unconsolidated materials derived through the breaking down of rocks. According to Ramann (1917) 'soil is formed of rocks that have been reduced to small fragments and have been more or less changed chemically, together with the remains of plants or animals that live on or in it'. J.S. Joffe (1949) has defined soil that 'the soil is a natural body of animal, mineral and organic constituents differentiated into horizons of variable depth, which differ from the material below in morphology, physical make-up, chemical properties and composition, and biological characteristics'. Thus the whole depth or zone of materials included in the category of soil is differentiated into (1) **true or toposil** which represents the uppermost layer of the soil and supports all types of plant life, and (ii) the **subsoil** which represents the weathered materials of the parent rocks but does not carry the nutrients and other properties of topsoil or true soil.

The soil is in fact the very heart of the life layer known as the biosphere because it represents a zone wherein plant nutrients are produced, held, maintained and are made available to plants through their roots and to the micro-organisms which live in the soil. The soil zone is considered to be a great **biological factory** because (i) the soil layer functions as a medium for the transfer paths of energy and matter and helps in the biological cycling of nutrients, (ii) a great varieties of organic compounds are generated in the soil layers, (iii) the soil layer provides home and ideal environmental conditions for living organisms of several varieties and numerous species, (iv) this is the soil layer where organic materials derived from plants and animals and minerals derived from the parent rocks are disintegrated and decomposed and are changed into elements, (v) necessary nutrients are made available to plants from the soil layer, (vi) soil layer holds water in storage which is used by plants and animals (which live in the soil) etc.

Besides, soil is also very significant environmental attribute for human society because (i) it is the basic medium for food and timber production, (ii) it provides foundation for buildings and roads, and (iii) it is very important natural exhaustible resource because it cannot be replaced if it is destroyed or lost through excessive soil erosion caused by antothropogenic activities.

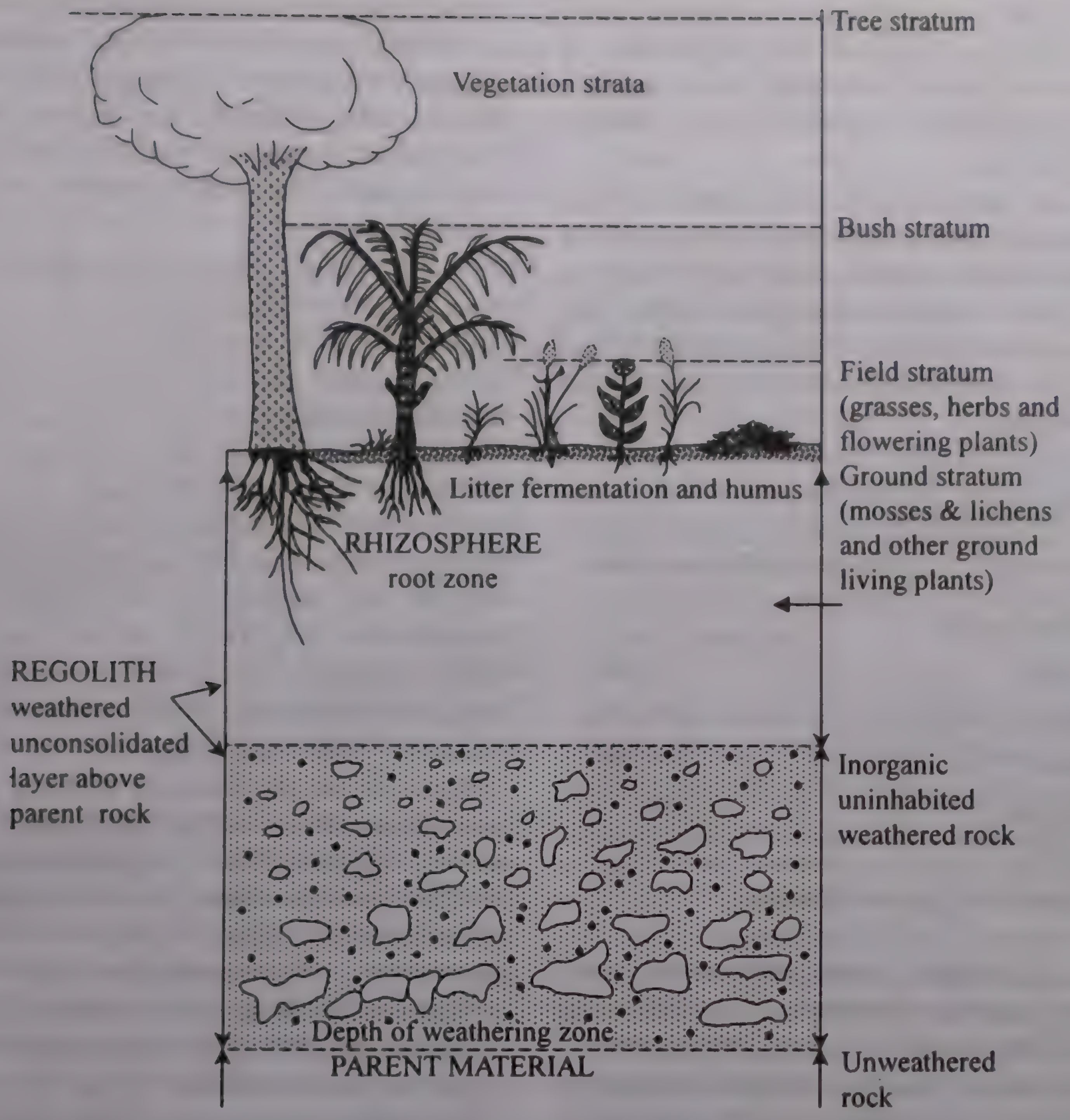

Tree stratum
Vegetation strata
Bush stratum
Field stratum (grasses, herbs and flowering plants)
Ground stratum (mosses & lichens and other ground living plants)
Litter fermentation and humus
RHIZOSPHERE
root zone
REGOLITH
weathered unconsolidated layer above parent rock
Inorganic uninhabited weathered rock
Depth of weathering zone
PARENT MATERIAL
Unweathered rock

Fig. 7.1 : Vertical section through the vegetation and soil system (based on P.A. Furley and W.W. Newey, 1983).

The soil system is the product of environmental and biological processes and is interrelated with climate, vegetation (flora), animals (fauna), underlying rocks, topography and time which also affect the biosphere. The comprehensive study of soil system in terms of is components, its classification, processes of its formation and its evolution through time is of vital significance because it is an integral part of the biogeographic system.

7.2 COMPONENTS OF SOIL SYSTEM

The composition of soils is generally studied through its vertical sections which are termed as **soil profiles** and these extend from the ground surface down to the unweathered parent rocks. If the whole length of vertical section right from the uppermorst stratum of the plant community down to the basal weathering surface or the upper surface of unweathered parent rocks is taken into account, two major zones are identified e.g. (i) **vegetation zone,** and (ii) **soil zone.** The vegetation zone consists of four strata viz. (i) tree stratum, (ii) bush stratum, (iii) field stratum (grasses, herbs, flowering plants and agricultural plants), and (iv) ground stratum (mosses, lichens and other plants which thrive on the ground surface). The soil zone consists of two layers or sub-zones viz. (i) The **solum** which contains loose unconsolidated weathered materials, organic matter and living organisms, (ii) **sub-soil zone** which contains inorganic matter and uninhabited weathered rocks known as regolith. Some times the whole zone of loose and unconsolidated weathered rock materials whether containing living organisms or not is called **regolith** (fig. 7.1).

There are four major components of soil system which need consideration for understanding the composition and characteristics of soil in a given area e.g. (1) flora, fauna and organic matter, (2) inorganic minerals, (3) soil solution, and (4) soil atmosphere. The following table (7.1) shows the components of soil.

Table 7.1 : Soil components

Major Components	Percentage Composition
1. Living orgnisms and organic matter	5-12%
2. Mineral matter	38-47%
3. Soil solution	15-35%
4. Soil atmosphere	15-35%

1. Flora, Fauna and Organic Matter

Living organisms (plants and animals) and organic matter together constitute 5 to 12% of the total composition of soil system. The organisms living in the ground or soils are called edaphons. It is very difficult task to differentiate the organisms living in the soils and in the ground from those organisms which live on the ground because most of the major groups of organisms are common to both the environments (soil environment and ground surface environment). The animals living in the soils vary in size, from 20 cm in length to less than 20 micrometers. The soil animals are classified into three groups viz. (i) macro-fauna, (ii) meso-fauna and (iii) micro fauna.

Macro animals living in the soils and organic litters are over one centimeter in length and these include both vertebrates and invertebrates of chordate phylum. The important species of chordata vertebrates are mammals (moles, shrews, armadillos, hares, rabbits, squirrels, gophers, rodents etc.), amphibians (legless and worm-like tropical amphibians etc.) and reptiles (some lizards and snakes). The invertebrate chordate macro-fauna include earth worms, snails and slugs insects, spiders, mites and ticks. **Meso-animals** of the soil environment are of the size ranging between one centimeter and 0.2 mm in length and these include smaller mites and majority of spiders, springtails, potworms, insect larvae, some millipeds and isopods. **Micro-animals** include the smallest organisms that live in the soil environment. The length of their body is usually less than 0.2 mm.

A few aspects of fauna like (i) the length of time spent by the fauna in the soils, (ii) their feeding habits, (iii) their habitats, and (iv) their movements or locomotion are significant from the standpoint of the development of soil characteristics. The soil fauna are divided into three groups on the basis of length of time spent by them e.g. (i) those soil animals which enter the soil environment when they become adult to take refuge during hibernation (like beetles and thrips), (ii) those soil insects which spend their early life in the soils as eggs or larvae (like butterflies, moths etc.), and (iii) those which spend almost whole of their lives (many invertebrate insects). The soil fauna are divided into five categories on the basis of feeding habits viz. (i) **carnivores** (like beetles, nematodes, mites, centipedes, molluscs etc.), (ii) **phytophages** (those fauna which feed in either plants standing above the ground or on roots of plants or on woody plant materials), (iii) **saprophages** (those soil animals which feed on dead and decomposed organic matter (earthworms etc.), (iv) **microphytic feeders,** which feed on spores, lichens, fungi, algae and bacteria (like mites, nematodes, springtails etc.), and (v) **composite animals** which feed on a variety of materials.

Form the standpoint of habitats soil animals are divided into three groups which are associated with three sub-layers or horizons of organic layer e.g. (i) soil fauna of litter horizons (or l horizon or layer of fresh litter), (ii) soil fauna of fermentation horizons (f layer or horizon of partly decomposed litters), and (iii) soil fauna of humus horizons (h layer or horizon of well decomposed litter and some times mixed with mineral matter).

Soil flora and micro-organisms include larger plants mainly their roots, fungi, bacteria, algae and soil protozoa. These organisms largely affect properties of soils of a given region. The bacteria and fungi are basically microbes which play very crucial role in the transfer and circulation of nutrients and flow of energy in the ecosystems. The

fungi are the chemosynthetic organisms representing various groups of soil organisms which perform a verity of duties in the soil zone viz. formation of mycorrhizas, breaking down of organic matter, attack on living organisms and introduction of several plant diseases. A few of the fungi are important commercial sources of antibiotic medicines and enzymes. **Bacteria** are the most important microbes of the soil zone because they play significant roles in (i) decaying wood and vegetation, (ii) decomposing organic matter, (iii) producing humus, (iv) cycling of nutrients etc. **Algae** are photosynthetic organisms and live in the upper surface of the soil horizons. They are very important to the soils because they (i) supplement the soil minerals with organic matter, (ii) play a cohesive role in binding the soil particles together, (iii) make the soil structure stable which protects the soil from excessive leacing and erosion, (iv) provide nutrients for higher plants, (v) help in the aeration of poorly drained soils, (vi) help in fixing the atmospheric nitrogen etc.

Organic matter includes dead and decomposed parts of living plants and animals. In other words, organic matter represents the 'non-living biomass' of plants and animals. The varied function of organic matter are very important to soil zone and the organisms of the biospheric ecosystem as it (i) provides nutrients to plants, (ii) is a major source of energy for majority of the soil organisms, (iii) helps in the formation of soils, (v) is enriched by continuous input of matter from plants and animals, (v) undergoes continuous process of its breakdown and decompositions and (vi) is constantly circulated, cycled and recycled. The organic matter of the soil zone is comprised of (i) 85% of dead organic matter together with products of decomposition, (ii) 10% of plant roots and 5% of edaphons. The edapthon consists of (i) 40% of bacteria and antinomycetes, (ii) 40% of other microflora (e.g. fungi and algae), (iii) 12% of earthworms, (iv) 3% of mesofauna, and (v) 5% of other macro-fauna.

2. Mineral Matter

Minerals are very important constituents of the soil zone because they help in the formation of soil. Minerals are included in the category of inorganic matter of the soils. It may be stated that soils are formed due to weathering of parent rocks but it is not always necessary that the mineral composition of a particular soil resting over a parent rock may conform to the mineral composition of the said parent rock because in many cases more than 90% of the parent materials are not related to the parent rocks rather they have been brought and deposited by water, wind, ice etc. The important minerals of the soi zone are olivine, hypersthene, augite, hornblende, biotite, potash, calcic plagioclase, calcic-alkali plagioclase, alkali-calcic plagioclase, alkali plagioclase, felspar, muscovite and quartz. There are continuous processes of reorganisation of texture and content of minerals breakdown of primary minerals, formation of secondary minerals and regrouping of organic matter and minerals into aggregates. The size of minerals increases with the increasing depth of the soil zone.

3. Soil Solution

The quality and quantity of water present in the soil zones affect the flora and fauna of the soil zones and the organisms mainly plants above the ground but having their roots in the soils. The presence of water in the soils is must because it helps in the preparation of soil solution containing nutrients which are taken up by the plants through their roots through the process of root osmosis. The amount of water held by the soils is determined by the rate of infiltration of rainwater and meltwater and the water retention capacity of soils. The infiltration rate refers to the amount of water percolating into the soils per unit time (usually measured in hour) which is controlleld by the strucutre and texture of soils, nature of organic matter and the amount of moisture already present in the given soil. On an average there are three rates of infiltration viz. (i) low rate (0.25 cm of water percolating downward per hour), (ii) moderate rate (1.27 to 2.54 cm per hour), and (iii) high rate (more than 2.54 cm per hour). The clay soils, loam soils and sandy soils account for low, moderate and high rate of infiltration respectively. On the basis of amounts of water retained in the soils with respect to soil volume three stages of the proportions of solid matter, water and air can be identified e.g. (1) **Saturated stage**-when all the voids and pores within the soils are filled with water. The saturated soils cannot hold further addition of water and thus there is throughflow of water. (2) **Field capacity stages**-when fifty percent of the total voids and pore spaces are filled with water and the remaining 50 percent are occupied by air. (3) **Wilting stages**—when soil water is lost through continued evaporation, uptake of water by plant roots etc. and thus no further water is available to soil organisms. Though at this stage even 25 percent of voids are still filled up with water but this water cannot be used by plants because water is tightly held against the colloidal surfaces. The saturated stage of the soil water is not useful for the organisms because it causes respiratory problem to soil organisms, damages root system of plants, causes death to microflora and fauna. Similarly, wilting stage of the soil water causes death of soil organisms. Thus the water held between field capacity and wilting statge is most suited to soil organisms.

4. Soil Atmosphere

The soil atmosphere component of the soil system includes the consideration of the presence of different gases and air, the movement of air within the soils and temperature distribution. It is important to note that there is variation in the proportion of oxygen and carbon dioxide of the aboveground atmosphere and the soil atmosphere as is evident from table 7.2

Tab.e 7.2 : Composition of the Soil and aboveground Atmopshere (in percent by volume)

	Oxygen	Carbon dioxide	Nitrogen	Water Vapour
1. Above-ground Atmosphere	20.97	0.03	79.00	<100
2. Grassland Soil	18.40	1.60	79.2	
3. Arable soil	20.70	0.10	79.2	Frequently 100

The concentration of CO_2 in the soil atmosphere is several times higher than the natural concentration of CO_2 in the above-ground atmoshere. This difference of carbon dioxide between the soil atmosphere and the above-ground atmosphere is because of the fact that there is continuous evolution of carbon dioxide due to decomposition of organic matter by the microscopic organisms in the soils. On the other hand oxygen is consumed by the plants through respiration and thus there is gradual depletation of soil oxygen (O_2) with the increase of soil organisms. The ratio between CO_2 production and O_2 consumption depends on a variety of factors e.g. the amount of moisture in the soil, soil temperature, the rate of decomposition of organic matter by the decomposers, the activities of organisms and plant roots in the rhizosphere or rootsphere etc. There is inverse relationship between the amount of soil water and soil air. If there is minimum amount of water in the soils (wilting stage), there is maximum air in the soil (the stage of well aerated soil or aerobic stage of soil), contrary to this, if there is maximum amount of water in the soil (saturated stage) there is minimum air in the soil (the stage of poorly aerated soil or anaerobic stage of soil environment). Thus the $CO_2 : O_2$ ratio in the aerobic soils is around 1 because plants consume maximum amount of oxygen but the $CO_2 : O_2$ ratio becomes more than 1 in the anaerobic soil because due to excess water plants are unable to consume required amount of oxygen as their respiration is retarded.

Besides oxygen, a few more gases are evolved due to decomposition of organic matter by the decomposers e.g. methane, ethylene, sulphides etc. It is evident that the water-air ratio in the soils is very crucial factor for the survival and growth of soils organisms particularly plants because abundant oxygen is required by the plant roots for the proper growth of vegetation . If the soils continue to be wet and over-saturated for longer period the amount of the air present in the soils becomes minimum and therefore the respiration by plants is retarded, with the result several plants die.

The soil temperature is very important factor for the growth of soil organisms. It is affected by a host of factors e.g. horizontal distribution of insolation and ground temperature from equator towards the poles, shades of vegetation, flux of heat energy into the soil, exchange of heat between the soil and air, retention power of heat by a given soil type, diffusion of heat by the soils, presence of organic matter in the soils etc. Soil temperature largely controls the activities of micro-organisms, enzyme activity and the biological processes that regulate plant growth e.g. seed germination, root osmosis etc. The decomposition of organic matter by the decomposers (microbes) and mineralization of the soils are directly related to temperature i.e. decomposition and mineralisation increase with the increase of soil temperature. The decomposition of organic matter is considerably slowed down when the soil temperature falls below 10^{0}C. Thus the organic matter is least decomposed in the colder regions and consequently there is greater accumulation of organic matter. Contrary to this, there is maximum decomposition of organic matter in the humid tropical areas and more and more nutrients, resulting from the decomposition of organic matter, are made available to plants for further use and thus there is maximum growth of vegetation.

7.4 SOIL STRUCTURE

The aggregation of individual soil particles in the form of lumps or clusters is called **soil structure.** A particular soil may have several structures wherein the aggregates or clusters of soil particles are separated from each other by natural surfaces of weakness i.e. cracks. The soil structure is in fact the physical property of the soil and is thus very important for agricultural practices because (i) the structural units of the soils indicate the air and water holding capacity of the soils, (ii) soil structure reflects the mineral and organic contents of the soils, (iii) soil structure determines the nature and lateral movement of water in the soil, (iv) soil structure determines the susceptibility of soil erosion, (v) the ease of cultivation and the capability of the soils for plant growth and management are determined by the soil structures etc.

An individual natural aggregate of soil particles is called a **ped** whereas an aggregate of soil particles resulting from the breakage during ploughing of the soils is called a **clad**. The shape, size and durability in terms of hardness or stability of peds are important properties of the soil structure. Peds are normally classified into four types on the basis of shape e.g. (i) platy, (ii) prismatic, (iii) blocky or angular, and (iv) spheroidal or granular. In **platy soil structure** peds are composed of plates or thin flat pies which are arranged in horizontal manner. The **prismatic soil strucutre** represents the vertical columnar position of peds. The peds in a blocky soil strucutre are angular in shape and of equal dimension whereas the peds are more or less rounded in the **spheroidal soil strucutre.**

The peds and even individual coarse mineral grains have the coatings of surface films of materials. Such coatings are called **cutons.** For example, a ped may be coated with clay. This is called as cutons of clay. The other cutons include coatings of oxides of iron, oxides of managanese on mineral grains and films of organic matter which surround a ped.

7.5 SOIL PROFILE AND HORIZONS

A soil profile is a display of vertical section from the ground surface down to the parent rocks. Thus a soil profile denotes the vertical distribution of soil components (e.g. the living organisms-flora and fauna-and organic matter, the inorganic minerals, the soil solution and the attributes of soil atmosphere, as discussed earlier) and various associations of the properties of these components. The soil profile is characterised by the following common properties.

(i) On an average there is gradual decrease of organic matter, number of living organisms, activity of living organisms etc. with increasing depth in the soil profile.

(ii) The level of aeration of soil decreases from the surface downwards in the soil profile.

(iii) There is increase in the number and variety of parent minerals from the surface downward in the soil profile upto the base of parent rocks.

(iv) There is no definite trend of either increase or decrease in the content of soil water with depth because there is a lot of fluctuation in water content. The content of soil water is determined by (i) the location of groundwater, (ii) nature of movement of groundwater, (iii) frequency and amount of rainfall, (iv) absorptive characteristics of different horizons of the soil profile.

It may be pointed out that some times the change of various properties of soil components with depth in the soil profiles is not simple, uniform and regular because many inorganic processes and living organisms through their activities transport, distribute and redistribute the materials in the whole profile and thus natural position of various characteristics is disturbed. The layers in a soil profile characterized by distinctive characteristics of physical and chemical composition, organic content, structure, etc. are called **soil horizons.** The characteristics of the horizon differ from the characteristics of the other horizon of a given soil profile.

Different soil horizons of a given soil profile having distinctive characteristics are developed due to action and interactions of climate, vegetation, animals and reliefs of a particular area over a long period of time. Some times the boundaries of a horizon (both upper and lower) are clearly observable and are well defined. In other words, one horizon may be easily differentiated from the other horizon of a soil profile. But some times the changes of soil properties with depth are so slow and gradual that the boundaries of different horizons of a soil profile are not well marked.

The soil horizons of soil profiles are basically divided into two broad categories e.g. (i) organic horizons (indicated by letter O), and (ii) mineral horizons.

(1) **Organic horizons** are the topmost layers of a soil profile and these contain organic matter whether dead or alive. These horizons are designated by the capital letter O. These layers are formed due to accumulation of organic matter which is derived from plants and animals. The organic or 0 horizon is further subdivided into two layers e.g. O_1 horizon and 0_2 horizon. O_1 horizon is the uppermost layer of the organic horizon and consists of the original form of vegetative matter as fresh litter and partly decomposed or comminuted litter (also called as litter layer and disignated by L for fresh litter and F for partly decomposed litter). Just below the 0_1 horizon lies the 0_2 horizon which is characterized by the altered remains of plants and animals. The plants and animals are so greatly altered through decomposition and comminution that the original form is beyond recognition without the help of microscope. The decomposed organic matter of the 0_2 horizon is called **humus** and the process of humus formation and therefore of the development of 0_2 horizon is called **humification.**

(2) **Mineral horizons** contain inorganic minerals of two types e.g. (i) skeletal minerals (e.g. quartz), and (ii) clay minerals. Besides, the upper layers of the mineral horizons also contain some limited amount of organic matter. There are significant variations even within the mineral horizons and therefore atleast 3 layers are identified within the mineral horizons and these layers/horizons are designated by capital letters A, B and C. Even within A, B and C horizons there are significant variations and therefore various subdivisions are recognized within each mineral horizon. These subdivisions or subhorizons are named by adding numerals with the horizon letters e.g. A_1, A_2,......B_1, B_2......etc. It may be pointed out that the properties of A and B horizons of soil profiles vary from one type of soil to the other type and from one climatic region to the other region. The following are the common characteristics of different horizons of mineral horizons of soil profile.

A_1-This horizon lying below the 0 horizon of organic matter is formed at or near the soil surface and is characterized by mixed zone of minerals and organic matter and by more biological activity. The horizon is of dark colour.

A_2-This is light coloured horizon which is characterized by maximum eluviation (movement) of silicate clays, oxides of iron and aluminium etc.

A_3-Transitional to B but this zone is more like A than B. It is not always present in all soil profiles.

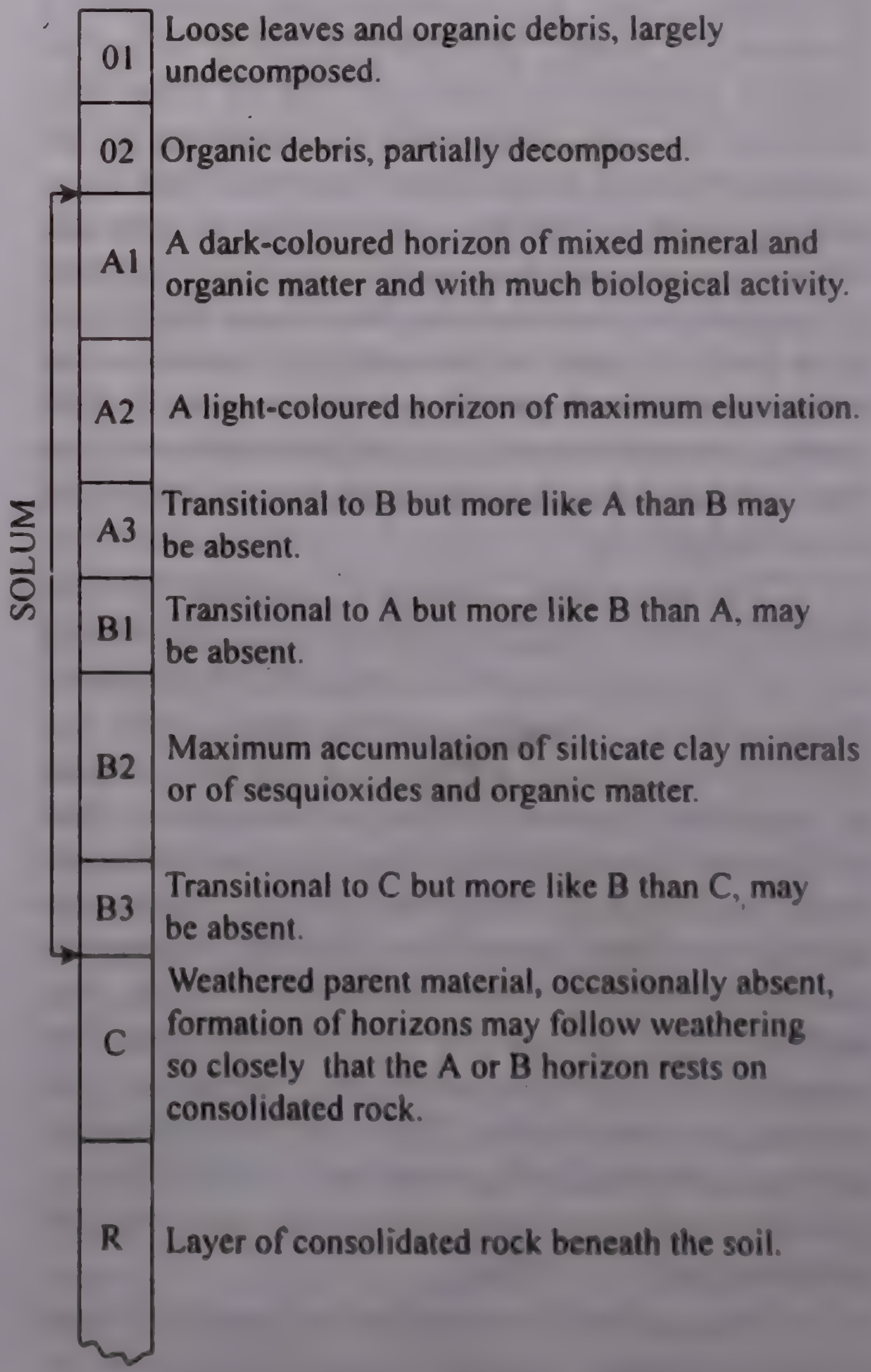

01
Loose leaves and organic debris, largely undecomposed.
02
Organic debris, partially decomposed.
A1
A dark-coloured horizon of mixed mineral and organic matter and with much biological activity.
A2
A light-coloured horizon of maximum eluviation.
A3
Transitional to B but more like A than B may be absent.
SOLUM
B1
Transitional to A but more like B than A, may be absent.
B2
Maximum accumulation of silticate clay minerals or of sesquioxides and organic matter.
B3
Transitional to C but more like B than C, may be absent.
C
Weathered parent material, occasionally absent, formation of horizons may follow weathering so closely that the A or B horizon rests on consolidated rock.
R
Layer of consolidated rock beneath the soil.

Fig. 7.2 : Horizons in generalized soil profile.

B_1-Transitional to A but more like B than A. This zone is not always present in soil profile.

B_2-This horizon is characterized by maximum illuviation (accumulation) of silicate clay minerals or sesquioxides (R_20_3) (Fe_20_3 + Al_2 0_3 + $Mn0_2$ + P_2O_5) and organic matter.

B_3-Transitional to C but more like B than C. This zone may be present or may be absent.

C- C horizon represents weathered parent materials (called regoliths) which are unconsolidated or weakly consolidated. This horizon is also called subsurface horizon but lacks in the properties of A_2 A_3 or B_2 horizons and retains the characteristics of the structure of the basal parent rocks. This is also called as glay layer.

D or R- D or R layer represents the layer of consolidated hard bedrocks beneath the soils.

It may be pointed out that there are variations within a single subhorizon (e.g. A_1, A_2, A_3, B_1, B_2 etc.) due to varying characteristics of soil components. Thus lowercase letters are added to the capital letters meant for designating major horizons (e.g. A or B) to reveal special and unique properties of particular soil horizon as given below :

b-buried horizon

ca-accumulation of carbonate matter (e.g. Bca)

f-soil frozen

g-mottled due to gleying (e.g. Ag. Eg, or Cg)

h-accumulation of humus (e.g. Ah or Bh)

ir-accumlation of iron (Bir or iron pan)

hir (accumulation of humus and iron)

p-horizon disturbed by ploughing (e.g. Ap)

si-accumulation of silica (e.g. Bsi)

t-accumulation of translocated clay (e.g. Bt)

x-brittle layer (fragipan)

Table 7.3 : Horizons of Generalized Soil Profile

Ground Surface		General Usage		More Recent Usage
		01 (Aoo)	L	Organic horizon, Litter Layer
		02 (Ao)	F	Organic horizon (decomposed organic matter)
	Zone of eluvation	A_1	H	Dark colour : rich in humus
		A_2	A	Light colour : zone of maximum eluvation (leaching or downward movement of minerals and organic matter)
		A_3	E	Transition to B
True Soil	Zone of illuviation (accumulation)	B_1		Transition to A
		B_2	B	Zone of maximum illuviation (accumulation of minerals)
		B_3		Transition to C
	Weathered parent materials	C		Unconsolidated weathered subsurface horizon, gley layer
	Solid bedrock	D	R	Solid bedrack.

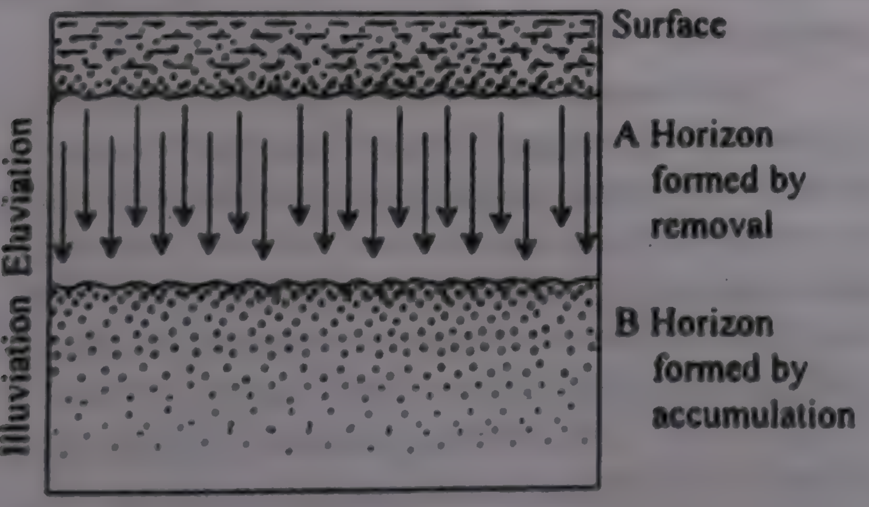


Fig. 7.3 : The processes of eluviation and illuviation leading to the formation of A and B horizons.

7.6 SOIL FORMATION

The soil is a dynamic layer of loose and unconsolidated materials because many physical, chemical and biological activities and processes operate simultaneously in the soil layer or profile. There is much variation in the soil forming processes which range from individual, small-scale and rapid events (like exchange of ions) to large-scale complex events and processes which operate very slowly. The formation of the soils in a particular region is the result of (i) soil forming processes, and (ii) the factors which affect the formation and development of soils.

1. Soil Forming Processes

The events and processes, whether physical, chemical or biological, which help in the formation of soils in a given region are called pedogenic processes or soil forming processes, which are classified into four groups. The formation of soil is, in fact, the result of the proportions of these processes over a definite time.

(1) **Soil Enrichment** : Soil enrichment is the process that includes all those events and processes which involve the addition of organic and inorganic materials to the soils. Various types of materials are added to the soil profile through a variety of pathways and mechanisms e.g. (i) Inorganic materials are added to the soil profile by exogenetic processes viz. running water, wind etc. The materials are derived through weathering and erosion of the soils by transporting agents like running water, wind etc. (ii) The mater and energy added to the soil surface (epipedon-surface horizon of the soil profiles) include solar energy (heat), rainwater having dissolved substances, atmospheric gases and dust, air-born organisms, organic matter, man-induced materials (fertilizers) etc. (iii) The organic materials derived from the litter (leaves) of plants accumulate in the 0 horizons of the soil profile and these organic materials produce humus, the process of humus formation is called humification. (iv) Addition of materials due to lateral movement of water in the soil layer includes soil particles, water, dissolved substances, migrating and transported organisms. (v) Addition of materials due to upward movement (capillary action) in the soil profiles includes dissolved substances from the groundwater and the materials brought to the soil surface by organisms (e.g. earthworms, ants and termites).

(2) **Losses from the Soils** : The loss of the materials of the soil body includes (i) loss of surface materials through lateral movement e.g. removal of materials by soil erosion caused by surface runoff, (ii) loss of radiation energy (heat) through evaporation and loss of water from plant leaves through transpiration, (iii) loss of gases (e.g. loss of nitrogen through the process of denitrification), (iv) removal of soil materials through lateral drainage within the soil profile, (v) loss of surface materials both organic and inorganic (minerals) from the soil surface to the lower horizons (through the processes of **leaching** or **eluviation** (fig. 7.3) (downward movement of water, dissolved and suspended organic and inorganic materials).

(3) **Translocation of Materials** : Translocations of soil materials involve two types of vertical movements in the soil profile e.g. (i) upward movement (**capillary action**), and (ii) downward movement (leaching or eluviation). These vertical movements take place when the ground surface is level but when the ground surface is sloping, lateral movement is more dominant. The process of **eluviation** involves the downward movement of fine particles (both mineral and organic from the upper soil horizon mainly from A_2 horizon). Thus due to transfer of fine particles downmard coarse particles are left in the upper soil horizon. These skeletal mineral grains left behind in the A_2 horizon include quartz and silica. The increase in the proportion of silica in the A_2 horizon (because of downward movement of finer materials) is called **silication.** The process of **illuviation** involves accumulation of materials (removed from the upper soil horizons and moved downward) in the lower soil horizons mainly B_2 horizon. The materials accumulated in B horizon include clay particles, organic matter (humus) or sesqui-oxides of iron and aluminium.

The process of **decalcification** involves the revoval of calcium carbonate due to reactions of carbonic acids with carbonate mineral matter in the upper horizon under the broader process of eluviation (removal of materials). The accumulation of carbonate minerals in the B horizon of illuviation zone is called the process of **calcification.** The process of the removal of salts is called as **desalinization** whereas the precipitation of soluble salts is known as **salinization**.

(4) **Transformatinos of Materials** :The process of the transformation of materials, both organic and inorganic, includes (i) the decomposition of primary minerals into secondary minerals, (ii) formation of new minerals and organic compounds due to decomposition of minerals and organic matter, (iii) humification (transformation of plant tissues into humus), and (iv) intimate mixture of organic and mineral matter.

It may be pointed out that the processes of translocations and transformations are theoretically separate but in most of the cases these two processes operate together. The following are the important processes of translocations and transformations.

Translocations

1. **Illuviation** : movement of materials from A horizon and accumulation in B horizon.
2. **Capillary action** : upward movements of dissolved or suspended matter by groundwater.
3. **Upward movements** : of matter by organisms e.g. earthworms, termites etc.
4. **Melanization** : darkening of the colour of a section of soil profile through organic matter.
5. **Leucinization** : (decoloration) : lightening of the colour of a section of the soil profile mainly in A horizon.
6. **Compaction** : physical reduction of the air content.
7. **Induration** : hardening of a section of the soil profile such as kankar pan, iron pan (ferricrete), calcrete, alcrete, silcrete etc.

Transformations

1. **Audification** : accumulation of H ions, mainly in surface horizon (epipedons)
2. **Neutralization** : counteraction of H ions
3. **Oxidation** : formation of iron oxides
4. **Reduction** : loss of oxygen ions
5. **Solution** : dissolution of slouble mineral into solution, e.g. calcium carbonate into bicarbonate
6. **Precipitation** : deposition of dissolved substances in solid form from solution
7. **Hydration** : swelling of minerals through the absorption of water resulting into the formation of new compounds
8. **Dehydration** : loss of water resulting into the return of the compound to original form
9. **Hydrolysis** : replacement of cations in a mineral structure by hydrogen ions from the soil solution
10. **Decomposition** : breakdown of mineral and organic materials through biochemical processes
11. **Humification** : formation of humus from original organic materials
12. **Mineralization** : release of minerals in various forms during the process of decomposition of organic matter

Combined Processes of Transformations and Translocations

1. **Silication** : accumulation of silica
2. **Desilication** : movement of silica out of a section of the soil profile
3. **Calcification** : accumulation of calcium carbonate mainly in C horizon.
4. **Decalcification** : movement of calcium carbonate out of a section of the soil profile
5. **Salinization** : accumulation of soluble salts in a section of the soil profile
6. **Desalinization** : movement of soluble salts out of a section of the soil profile
7. **Alkalization** : accumulation of Na ions and rise in soil pH
8. **Dealkalization** : movement of Na ions out of a section of the soil profile
9. **Pedoturbation** : disruption of soil horizons by biological (root pressure, burrowing by animals and most of the human activities), physical and chemical activities (wetting and drying, swelling and contraction, freezing and thawing etc.)
10. **Stabilization** : artificial and natural processes of making the soil horizons stable

2. Factors Affecting Soil Formation

The processes of soil formation and the properties of the soils are affected and determined by a combination of 5 basic factors e.g. (i) climate, (ii) biotic factors or organisms, (iii) relief or topographic factors, (iv) parent materials, and (v) time. The factors affecting the soil formation have been presented in the form of an equation by H. Jenny (1941) as given below :

Soil is the function of climate, organisms, reliefs, parent materials and time.

$$S = f(cl, o, r, p, t\ldots\ldots)$$

Where cl = climatic factor

o = organisms or biotic factor

r = relief or topographic factor

p = parent material

t = time factor

S = soil or soil profile

Dots in the equation are meant for the inclusion of other factors which may be of local importance.

(1) Climate

Climate affects the moisture content of the soil and the temperature which in turn affect the soil forming processes. In fact, the properties of the soils are largely affected by the amount of soil water and the movement of water in the soil profile. The downward movement of water helps in the formation of soil horizons through the processes of **eluviation, illuvation, humification** and **mineralization** of organic matter. In the areas of heavy rainfall (e.g. humid tropical climates), the amount of soil water increases enormously which leads to greater amount of dissolution of soluble elements, transfer of these dissolved materials from the surface horizon, increase in eluviation, decrease in pH level and therefore increase in the acidification of the soils.

The temperature largely affects the rates of chemical, physical and biological reactions within the soil profile. The rise in temperature accelerates the speed of chemical reactions and biological decomposition. The combination of temperature and moisture of the soil affects the rate of chemical weathering and bacterial activity. For example, clay proportion and decomposition of organic matter by bacteria greatly increase in the regions characterized by high temperature and high humidity (warm and humid tropical climates). Climate largely affects the surface materials through erosion and weathering and the parent materials through weathering. It is the weathering of the parent rocks which leads to the formation of soils.

(2) Parent Materials

The weathering of parent rocks is a prerequisite condition for the formation of soils in any region. The composition of the soil profile in terms of primary and secondary minerals is directly influenced by the composition of the parent rocks. The structure of the original rocks (e.g. degree of consolidation, nature of cementation, bedding planes, joints etc.) also influences the properties of the soils. A particular rock having certain chemical and physical characteristics, is subjected to weathering which results into the breakdown of the rock into a mixture of soluble and insoluble materials. Some soluble materials are washed out by surface water and are brought to the rivers while the insoluble materials remain as residues which help in the formation of soils.

(3) Topography

Relief or topographic factors greatly influence the formation of the soils. Topography determines the nature of drainage and erosion which in turn affect the soils forming processes and therefore the properties of the soils of a given locality. The flat upland surface is characterized by ideal drainage and least erosion and therefore well leached thick soils are formed whereas flat but lowland surfaces are characterized by poor drainage and hence thick gleyed soils are formed. Slope is an important factor in affecting the formation of soils. The slope gradient, slope length and slope aspect (direction of slope in relation to the sun) affect the physical, biological and chemical properties of the soils.

(4) Organic Factor

The organic factors which influence the formation of the soils include vegetation, animals and micro-organisms. Various characteristics of plants viz. leaf fall, canopy, stem flow (flow of rainwater through the stems of plants), root system, competitiveness etc. influence and modify the characteristics of the soils of a region. The nature of tree canopy (dense or sparse, perennial-full of leaves throughout the year or seasonal) affects the soil moisture and soil temperature. The chemical composition of leaf litter largely determines the chemical properties of the soils. Grasses and legumes contain higher percentages of potassium and magnesium than the leaves of the trees. The roots of plants penetrate in the soils and weathered materials and thus modify the soils properties because these provide new routes for air, water and organisms into the soil. The roots also help in the binding of soil particles together and thus assist in the formation of soil aggregates (peds). The plants provide organic matter of the soils.

Animals paly a major role in influencing the major soil forming processes e.g. transformations and translocations. The macro and meso-fauna affect and modify the soil properties through burrowing, transporting and mixing of organic and inorganic materials. Rabbits, moles, prairie dogs, ground squirrels, beavers, rats etc. are amongst the largest modifiers of the soils. Among the mesofauna which modify the soils, important are earthworms, mites, springtails, termites etc. Micro-organisms decompose the organic matter.

7.7 CLASSIFICATION OF SOILS

The soils of the world have been classified in a veriety of ways on different bases. Russian scientists took initial lead in the development of **pedology** (the science of soils) and the classification of soils. The Russian geologist, V.V. Dokuchaiev, related the development of soil to the climate and vegetation of a given region. Thus the Russian scientists 'based their classifications of soils on the association of soil types with the climatic and vegetation zones' in the early twentieth century. G.F. Marbut, an U.S. scientist, presented a scheme of **Comprehensive System of Soil Classification** in 1938 which is recognized as USDA (United States Department of Agriculture) system. According to this system soils at the global level were divided into three orders e.g. (i) **zonal soils,** (ii) **intrazonal soils,** and (iii) **azonal soils.** The American pedologists presented a new system of soil classification named as the **Comprehensive Soil Classification System** (CSCS) in 1960. This system was initially named as **the Seventh Approximation** because it was seventh in the series of revisions of the system of soil classification since 1950. The classification system of the CSCS is also called **soil taxonomy.** The other significant soil classifications at global level include the schemes of **American Soil Taxonomy** presented by the Soil Survey Staff in 1975, Soil Type based on bioclimatic zones as presented by E. Bridges in 1978, Soil Orders presented by H.D. Foth in 1978, Soil Classifications based on diagnostic horizons developed by FAO (Food and Agricultural Organisation of the UNO) and UNESCO (United Nations Educational, Scientific and Cultural Organizations) etc.

In fact 'there are almost as many classifications and distributions of soils as there are soil scientists' (P.A. Furely and W.W. Newey, 1983). The soils have been classified at global, regional and local levels on various bases e.g. age of the soils, zonality of the soil distribution, bioclimatic zonaiton, character of soil horizons, physical properties of soils and associated processes, chemical properties and associated process, biochemical properties. A few schemes of the classifications of world soils are discussed below :

1. USDA System of Soil Classification 1938

The U.S. Department of Agriculture System of Soil Classification recognizes three orders of soils e.g. (i) zonal soils, (ii) intrazonal soils, and (iii) azonal soils.

(i) **Zonal soils** represent fully matured soils which have developed under the conditions of good soil drainage. These are the result of interplay of climate and vegetation over a long period of time. Zonal soils are characterized by full development of almost all of the soil horizons, their number and characteristics may vary according to local conditions and degree of human interference. Within the zonal order of soils there are 6 suborders and 21 great soil groups.

(ii) **Intrazonal soils** are formed in those areas where there is water-logging and therefore there is very poor drainage, regolith is endowed with high content of calcium carbonate and there is high content of soluble salts and sodium. These soils are divided into 2 suborders and 12 great soils groups.

Table 7.4 : Zonal Soils

Suborders	Great Soil Groups
I. Soils of the cold zone	1. Tundra soils
II. Light-coloured soils of arid regions	2. Desert soils 3. Red desert soils 4. Sierozem 5. Brown soils 6. Reddish brown soils
III. Dark-coloured soils of the semi-arid, subhumid and humid grasslands	7. Chestnut soils 8. Reddish chestnut soils 9. Chernozem soils 10. Prairie soils 11. Reddish prairie soils
IV. Soils of the forest grassland transition	12. Degratded chernozem soils 13. Non-calcic brown or Shantung brown soils
V. Light-coloured podzolized soils of forested regions	14. Podzol soils 15. Brown podzolic soils 16. Gray-brown podzolic soils

VI. Lateritic soils of forested subtropical and tropical regions	17. Yellow podzolic soils 18. Red podzolic soils (and terra rosa) 19. Yellowish brown laterite soil 20. Reddish-brown lateritic soils 21. laterite soils

Table 7.5 : Intra-zonal Soils

Suborders	Great Soil Groups
I. Halomorphic (saline and alkaline) soils of imperfectly drained arid regions and littoral deposits	1. Solonchak or saline soils 2. Solonetz soils 3. Soloth soils
II. Hydromorphic soils of marshes, swamps, seep areas and flats	4. Meadow soils 5. Alpine meadow soils 6. Bog soils 7. Half bog soils 8. Planosols 9. Groundwater podzol soils 10. Groundwater laterite soils
III. Calomorphic soils	11. Brown forest soils 12. Rendzina soils

(iii) **Azonal soils** do not have well developed soil horizons, rather there is uniformity in the soils from the top-surface to the base. There may be a variety of reasons for non-development of soil horizons in azonal soil e.g. (1) lack of sufficient time, (2) steep slopy terrain, (3) renewal of soils every year because of deposition of new materials as in the case of flood plains etc.

Table 7.6 : Azonal soils

Suborders	Great Soil Groups
	1. Lithosols 2. Alluvial soils 3. Sandy soils

The USDA System of soil classification (1938) was revised in the 1940s because this system was considered by many soil scientists as inadequate because (1) this classification was primarily based on the American experience and examples; (2) there was a flood of new information on soils due to researches carried out at regional and local levels in the different parts of the globe; (3) the system could not properly accommodate and represent the soils of the tropical regions; (4) the classification was based on assumptions and axioms regarding the relationships between the properties of soils and the roles of climate; (5) the lack of precision in definitions; (6) more emphasis on undisturbed or virgin soils etc.

2. Comprehensive Soil Classification System (CSCS), 1975

The Soil Survey Staff of the U.S. Soil Conservation Service prepared an exhaustive but scientific scheme of the classification of the world soils in 1975. The scheme is known as Comprehensive Soil Classification System (CSCS) which is also called Soil Taxonomy. The CSCS of soils classification is based on a hierarchy of 6 categories or levels of classification.

Levels	Categories (from higher to lower)	Number of soil classes recognized so far
1	Orders	10
2	Suborders	50
3	Great Soil Groups	225
4	Subgroups	1000 (only in the U.S.A.)
5	Families	5000 (only in the U.S.A.)
6.	Series	10,000 (only in the U.S.A.)

It may be pointed out that the recognized number of the first three categories of soils (e.g. Orders, Sub-orders and Great groups) may remain almost the same because they include almost all the soils of the world but the numbers of the last three categories (e.g. Subgroups, Families and Series) are subject to phenomenal increase if the researches of soil studies at continental, regional and local levels advance and the soils of all the continents are known and are included in the classification.

(A) Order and Suborders of Soils :The soils of the world have been classified by the CSCS into 10 orders of the highest category on the basis of the characteristics of diagnostic horizons of the soil profiles. Soil horizons have been divided into two groups e.g. (A) **epipedons** and (B) subsurface diagnostic horizons.

(A) **Epipedons** represent the horizon of the upper surface of the soils and are darkened by organic matter. Five types of epipedons have been identified.

(i) **Mollic epipedon** (Latin word Mollics, soft) is relatively thick surface horizon of dark colour due to organic matter mainly humus.

(ii) **Umbric epipedon** (Latin word Umbra, shade, dark) resembles the Mollic Epipedon in colour (of dark colour), structure and organic matter but the base saturation is less than 50 percent.

(iii) **Antropic epipedon** is similar to Mollic Epipedon but contains high amount of phosphorous due to continued farming for a long time.

(iv) **Plaggen epipedon** (German word Plaggen, sod) represents a layer of 50 cm thickness which has been created by human activities e.g. long continued farming and manuring.

(v) **Histic epipedon** (German word Histos, tissue) represents thin surface horizon which is seasonally saturated with water (at least for 30 consecutive days). This horizon of peat contains high organic carbon.

(vi) **Ochric epipedon** (German word Ochros, pale) is hardly a horizon because it is very thin, very light in colour and it contains very low amount (less than 1 percent) of organic matter.

(B) **Subsurface Diagnostic Horizons** are formed below the soil surface. The may be, in many cases, as parts of A horizon or B horizon of the soil profiles. About 16 principal subsurface horizons have been identified under the CSCS scheme by the U.S. Soil Survey Staff (1975).

(i) **Argillic horizon** (Latin word, argilla, means' 'white clay') is characterized by the accumulation of clay minerals through the process of illuviation (accumulation of materials). This horizon normally represents B horizon and is formed below the eluviation (movement, leaching) horizon (called A1 horizon).

(ii) **Agric horizon** (Latin word, ager, means 'field') represents a compact horizon and contains greater amount of silt, clay and humus. This horizon is formed after continued farming.

(iii) **Natric horizon** (Latin word, natrium, means 'sodium') is similar to Argillic Horizon but it has prismatic (columnar) structure and high proportion of sodium ions.

(iv) **Spodic horizon** (German word, spodos, means 'wood ashes') represents accumulated sesquioxides of aluminium with or without iron. It may/may not cantain organic matter.

(v) **Cambic horizon** (Latin word, cambiar, means 'to exchange') is changed or altered horizon with loss of iron and original structure of the parent materials.

(vi) **Oxic horizon** (French word, oxide, means 'oxide') repesents highly weathered horizon of 30 cm thickness having kaolinite as clay mineral.

(vii) **Calcic horizon** contains high amount of calcium carbonate or magnesium carbonate of secondary concretions. This horizon is more than 15 cm thick.

(viii) **Gypsic horizon** is enriched by the accumulation of hydrous calcium sulphate (gypsum) and is more than 15 cm thick.

(ix) **Salic horizon** is composed of more soluble salts than gypsum and is more than 15 cm thick.

(x) **Albic horizon** (Latin word, albus, means 'white') lacks in clay and free iron oxides which have been removed through the process of eluviation. This is almost sanday horizon.

(xi) **Duripan horizon** is indurated horizon representing 'hard pan' cemented by silica or aluminium silicate.

(xii) **Fragipan horizon** consists of loam and platy structure. It becomes brittle when it is wet but it becomes hard when it is dried up.

(xiii) **Plinthite horizon** is highly weathered and is poor in humus content but rich in sesquioxides. It hardens to become hard crust or hard pan.

(xiv) **Placic harizon** consists of thin iron pan which is cemented by iron and manganese.

(xv) **Sombric horizon** is freely drained and it contains illuvial humus (accumulated humus, leached from above).

(xvi) **Sulphuric horizon** contains mineral or organic soil material with very low pH (between 3-4).

The soils at global levels have been grouped into 10 orders representing the highest category of the hierarchy of soil classification. The soil orders have been based on the following criteria-(i) gross composition of the soils in terms of organic matter or minerals or even both (the composition of organic or mineral matter is expressed in terms of percentage), (ii) degree of the development of soil horizons in the soil profiles, (iii) presence or absence of diagnostic horizons, (iv) degree of weathering of the soil minerals which is expressed as cation exchange capacity (CEC) or as percent base saturation (PBS). The following are 10 major types (orders) of the world soils.

Category A (not recognised by the CSCS)

This category includes the soils which have poorly developed horizons or even do not have any horizon. The minerals of these soils can be further altered.

ORDERS	SUBORDERS
I. Entisols Weakly developed soils with no horizon	**1. Aquents** Seaonslly saturated with water, generally gleyed.
	2. Arents Pedogenic horizons disturbed by human activities mainly ploughing and spading.
	3. Fluvents Formed from recent alluvium, rarely saturated with water, usually stratified.
	4. Psamments Soils of sandy or loamy sand textures, parent materials usually dune sands or beach sands.
	5. Orthents Soils with loamy or clay textures.
II. Inceptisols Soils having weakly or quickly developed horizons, young to moderately developed soils containing weatherable minerals	**6. Aquepts** Soils of wet place, seasonally saturated with water, a gray subsoil, gleyed soil.
	7. Andepts Soils having high content of clays, humus and silica, developed from volcanic ash.
	8. Tropepts Soils developed in tropical climatic areas having brownish or reddish horizon of altered materials.
	9. Umbrepts Soils having dark acid surface horizon of organic matter, crystalline clay minerals, occur in moist midlatitude and high latitude climates mostly on steep slopes.
	10. Ochrepts Soils having thin or light coloured surface horizon of altered materials at or close to the surface with little organic matter.
	11. Plaggepts Soils with a plaggen epipedon, thick surface horizon of materials added by man through continued farming and manuring.

Category B (not identified by the CSCS)

This includes those soils which have higher propotion of organic matter.

III. Histosols Histosols are those soils which have very high content of organic matter in the upper 80 cm of the soil horizon.	**12. Fibrists** Soils with least decomposed organic matter, have fibrous and woody peats, saturated with water during most of the year.
	13. Folists Soils consisting of slowly decomposing forest leaves, resting on bedrock.
	14. Hemists Soils saturated with water during most of the year, contain semi-decomposed organic matter.
	15. Saprists Soils saturated with water during most of the year, have thoroughly decomposed organic matter.

Category C (not identified by the CSCS)

This category includes those soils which have well developed horizons and fully weathered minerals.

IX. Oxisols Oxisols represent those soils which are very old and highly weathered. These represent the soils of low latitudes and contain oxic horizon.	**16. Aquox** The soils of dominantly gray, or mottled dark red and gray colour, seasonally saturated with water.
	17. Humox The soils having humus-rich A horizon, found in cool moist regions, very large accumulation of organic carbon, occur on high plateaux.
	18. Orthox The soils of warm humid regions, mainly of equatorial areas.
	19. Torrox The soils of hot and dry climates, have dried horizons for more than 6 months of the year, not darkened by humus.
	20. Ustox The soils of drier climates, mainly wet-dry tropical climate.
V. Ultisols Ultisols represent the soils developed in a variety of climates e.g. moist sub-tropical climate, wet-dry tropical climate and monsoon	**21. Aquults** The soils seasonally saturated with water, gray in colour.

climate. These form under forest cover. B horizon of well drained ultisols is red or yellowish brown in colour. These soils contain accumulated clay. They are mostly found in S.E. United States of America, Southern China, Bolivia, Southern Brazil, Western and Central Africa, India, Burma, East Indies, N.E. Australia etc.	**22. Humults** The soils having high to very high content of organic matter, formed under high rainfall in middle and law latitudes. **23. Udults** The soils having moderate to small amount of organic matter, reddish or yellowish B horizons, and formed in warm temperate to hot humid climates. **24. Ustults** The soils of sub-humid climate. **25. Xerults** The soils having low to moderate organic matter, reddish to brownish horizons, develop in Mediterranean climate (cool moist winter and warm dry summer).
VI. Vertisols Vertisols have the following properties, (i) high content of clay (montmorillonite) which swells on hydration and shrinks on dehydration, (ii) wide deep cracks during dry season, (iii) movement of soil during wet season. These soils generally form under grass or savanna vegetation in sub-tropical and torpical climates charcterized by wet and dry seasons. These soils are locally called as black cotton soils, tropical black clays, regur etc. These are exclusively found in tropical areas (e.g. Deccan plateau of India, Sudan region of East-Central Africa, north-south belt in eastern Australia etc.)	**26. Torrerts** The soils having deep wide cracks almost throughout the year due to dry conditions. **27. Uderts** The soils developed in moist conditions, having open cracks for less than 3 months, usually for 60 days in continuation. **28. Usterts** The soils developed in wet-dry tropical climate, have open cracks for 90 days, cracks open and close twice in a year. **29. Xererts** The soils developed in Mediterranean climate, remain dry for long period, cracks are open for 60 consecutive days.
VII. Alfisols Alfisols are characterized by the following properties, (i) moist soils with B horizon of clay accumulation, (ii) horizons of gray, brown or red colour, (iii) surface horizon not darkened by humans, (iv) water available to plants for at least 3 consecutive months. These soils are found mostly in Central	**30. Aqualfs** These are gray in colour and are seasonally saturated with water. **31. Borals** These are the soils of cold climates and are formed either under boreal forests or on high mountains. These are characterized by (i) gray surface horizon, (ii) browinsh sub-surface horizon etc.

North Ameria, Europe, Central Siberia, North China, Southern Australia, eastern Brazil, western, eastern and southern Africa, northern Australia, eastern India etc. These are, on an average, agriculturally productive soils.	**32. Udalfs** These soils are formed in temperate or warm humid climates of deciduous forests. **32. Ustalfs** These soils have developed in sub-humid climates. The soils remain dry for 90 consecutive days and are of brownish to reddish colour. **34. Xeralfs** These soils have formed under Mediterranean climatic conditions characterized by cool, moist winters and dry summers. They are of brownish to reddish colour.
VIII. Spodosols The spodosols are characterized by the following-properties, (i) bleached gray to white A2 horizon, (ii) B horizon of accumulated dark materials including organic materials, compounds of aluminium iron, (iii) strongly acidic and low in plant nutrients, (iv) low in humus content, (v) sand texture and low water-holding capacity. These sols are supposed to have been formed genrally under forest cover of cool and moist midlatitude climates. These are agriculturally poor soils because of their low productivity.	**35. Aquods** The soils are seasonally saturated with water. These are characterized by black or white surface horizon lacking iron oxides; black, brownish or reddish B horizon etc. **36. Ferrods** These soils are of rare occurrence. These have accumulation of free iron oxides in B horizon. **37. Humods** Upper part of B horizon has accumulated humus and aluminium but no iron. **38. Orthods** B horizon is rich with the accumulated iron, aluminium, and humus.
IX. Mollisols Mollisols have the combination of the following properties, (i) very dark to black surface horizon of a mollic epipedon, (ii) thick profile, (iii) loose structure when dry, (iv) dominance of calcium in A & B horizons, (v) dominance of crystalline clay minerals, (vi) nearly black colour. Mollisols form under grass cover of dry-wet climates of middle latitudes and subtropical areas. These are mostly found in the U.S.A. (Great Plains region, Columbia Plateau,	**39. Albolls** These soils have bleached gray to white upper albic horizon and subsurface horizon of the accumulation of clay. **40. Aquolis** These soils have nearly black surface above and mottled grayish B horizon below. These are seasonally saturated with water. **41. Borolis** These soils represent the areas of cool semi-arid steppes and high mountains. These include chernozem soils, chestnut soils and brown soils

northern Great Basin, along the Gulf Coastal Plain, Yucatan Peninsula, etc.), South America (Pampas of Argentina and Uruguay), Eurasia (from Rumania across Russian Steppes, Siberia and Mongolia to Manchuria). Mollisols are well developed and fertile soils and are world-wide known for food-grains and seed grains.	**42. Rendols** These are formed on highly calcaeous parent materials in moist climates under forest vegetation. **43. Ustolls** These soils are characterized by a horizon of accumulation of soft, powdery calcium carbonate at a depth of about 50 to 100 cm. These soils are dry for at least 90 days. **44. Udolls** These soils are formed in temperate or warm humid climates. There is no accumulation of calcium carbonate in soft powdery form. **45. Xerolls** These soils are formed in sub-arid climates characterized by long dry period, mainly Mediterranean climate.
X. Aridisols Aridisols are characterized by the combination of the following properties, (i) lackof darkened surface horizon, (ii) lack of water for plants during most part of the year, (iii) low organic matter, (iv) absence of deep wide cracks, (v) large accumulation of carbonates at depth. These soils form under semi-desert and desert climate where there is very scantly rainfall which cannot enter the soils. Most of the deserts of the world represent these soils which are used for nomadic grazing.	**46. Argids** These include desert soils ard red desert soils.These have B horizon of accumulated clay. **47. Orthids** These soils do not have the horizon of accumulalted clay horizon. Some sub-types of these soils have salic horizon (of salt accumulation) which appears as a white layer.

Evaluation of CSCS

The detailed classification of world soils under the Comprehensive Soil Classification System (CSCS) prepared by the Soil Survey Staff of the U.S. Soil Conservation Service in 1975 has the following characteristics which make this scheme of soil classification more useful and advantageous than the other schemes.

- The classification is based on such field and laboratory data which can be identified in the field and measured in the field and laboratories.
- The classification uses the nomenclature derived mostly from Greek and Latin languages.
- The classification pays more attention towards the classification of soils rather than the soil forming processes.
- The classses of soils have been strictly defined in terms of the characteristics of the soils (morphology and composition of the soils). The definitions have been made to the largest extent on quantitative basis.

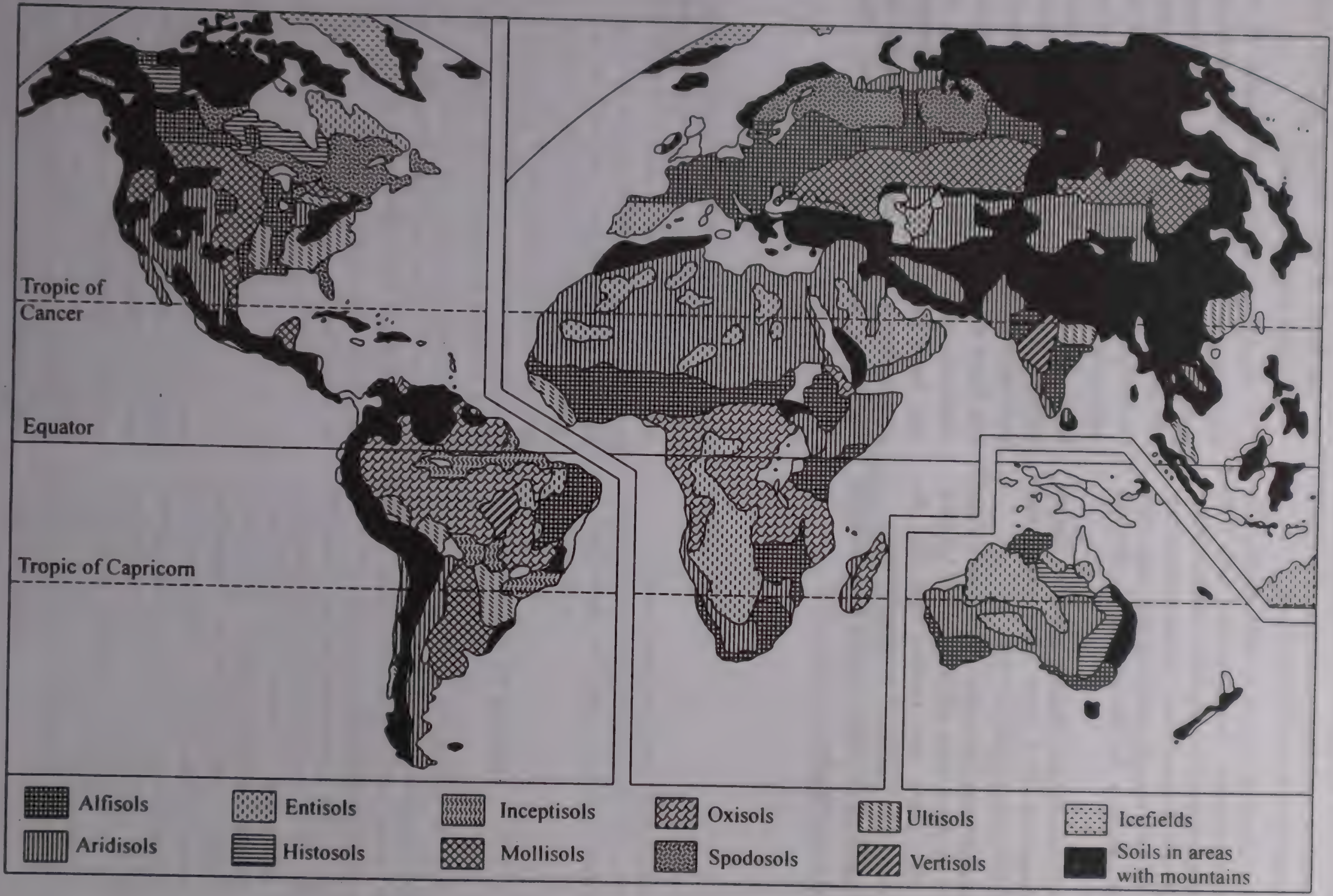

Tropic of Cancer
Equator
Tropic of Capricorn
▦ Alfisols
▥ Aridisols
▒ Entisols
▤ Histosols
▒ Inceptisols
▩ Mollisols
▨ Oxisols
▒ Spodosols
▥ Ultisols
▨ Vertisols
▒ Icefields
■ Soils in areas with mountains

Fig. 7.4 : World Soil Orders according to Comprehensive Soil Classification System (CSCS, 1975) as prepared by the U.S. Soil Survey Staff.

- The definitions of different soil classes have been based on such features of the soils which can be directly observed in the field.
- The classification does not make distinction between soils (well drained upland soils with full development of soil horizons) and intrazonal soils (poorly drained soils) in the highest category of the classification of the soils (the highest category in this scheme is the **soil order**).
- The soils modified by human activities (farming, manuring etc.) have been given due weightage in this classification.
- The classification has wider scope to cover and include all those soils which have not till now been discovered and studied but may be discovered and studied in coming future.
- The classification gives a greater uniformity to the soil classification.
- The soils profiles have been distinguished on the basis of their surface horizon (epipedon) and sub-surface horizons.

Inspite of several advantages of the Soil Taxonomy of the CSCS the classification also has some disadvantages e.g. (i) Very difficult nomenclature of Greek and Latin origin has been used in the classification, which becomes very difficult to understand for the students of other languages, (ii) More emphasis has been given to laboratory data which may not be possible in many of the developing and under-developed countries. "This classification has many merits as a scientific and a rigorous basis unrelated to the earlier, often confused, terminology, but it has not been adopted everywhere, and it seems that it may remain, as simply one more interesting soil classification" (M.J. Bradshaw, 1977).

8

ECOLOGICAL PRODUCTION AND ENERGY FLOW IN THE ECOSYSTEM

As described in the 6th chapter the biosphere is the largest ecosystem. There is input of matter and energy in the ecosystem to build biological structure, to reproduce and to maintain necessary internal energy level so that the ecosystems may function properly. There is also export of matter and energy from the ecosystems. When there is balance between the input of matter and energy and output (exit) of matter and energy, the ecosystems tend to be in equilibrium state. All organisms in the biosphere are like machines because they use energy to work and convert one form of energy into another form of energy. The energy pattern and flow are governed by the first and the second laws of thermodynamics.

First Law

The first law of thermodynamics is known as the conservation of energy which states that in any system of constant mass, energy is neither created nor destroyed but it can be transformed from one type to another type (example, electrical energy can be converted into mechanical energy). In terms of ecosystem, energy inflow or energy input into the system will be balanced by energy outflow from the system.

Second Law

The second law of thermodynamics states that when work is done, energy is dissipated and the work is done when one form of energy is transformed into another form.

8.1 SOURCES OF ENERGY

All sources of energy of the biospheric ecosystem are virtually out side the biosphere. The major source of energy is the solar radiation and other minor sources of biospheric energy are cosmic radiation, geothermal energy and energy subsidies released from storage in fossil fuels. The sun is the most important source of energy for the proper functioning of the ecosystem because the solar radiation is converted by green plants into food or chemical energy which is used by plants themselves, animals and man. Solar radiation also helps directly and indirectly in the circulation of matter in the biospheric ecosystem (the process is called as biogeochemical cycles comprised of water or hydrological cycle, chemical elements cycles, sediment cycle etc.)

The flux or inflow of solar energy in the biosphere has been estimated differently by various scientists. Following the estimate of Ian Simmons (1982) the solar energy reaching the top of the earth's atmosphere is 520 × 10^{22} Joules (which is $^1/_2$ billionth part of total energy radiated from the sun) every year. Out of this total energy (transmitted from the sun in the form of electromagnetic radiation) about 100 × 10^{22} Joules reach the earth's surface but 40% of the total solar energy entering the earth's atmosphere is reflected back into space by desert, snow and ice and oceans. Thus 60 × 10^{22} Joules become available to the green plants for photosynthesis. This part of the solar energy is known as **pool for photosynthesis.** This energy is converted by the green plants into food or chemical energy of which a large part is spent by the plants through respiration. Only 170 × 10^{19} Joules (which is only 0.2% of the total energy entering the earth's atmosphere) are stored in the biomass (the total mass of the living plant tissues). Thus it is obvious that the flora of the biosphere utilize only 0.2% of the total energy present in the light (solar radiation) of the right wavelength (suitable for photosynthesis by green plants). Man utilizes only less than one percent of the total energy stored in the biomass as accumulated organic matter (fig. 8.1).

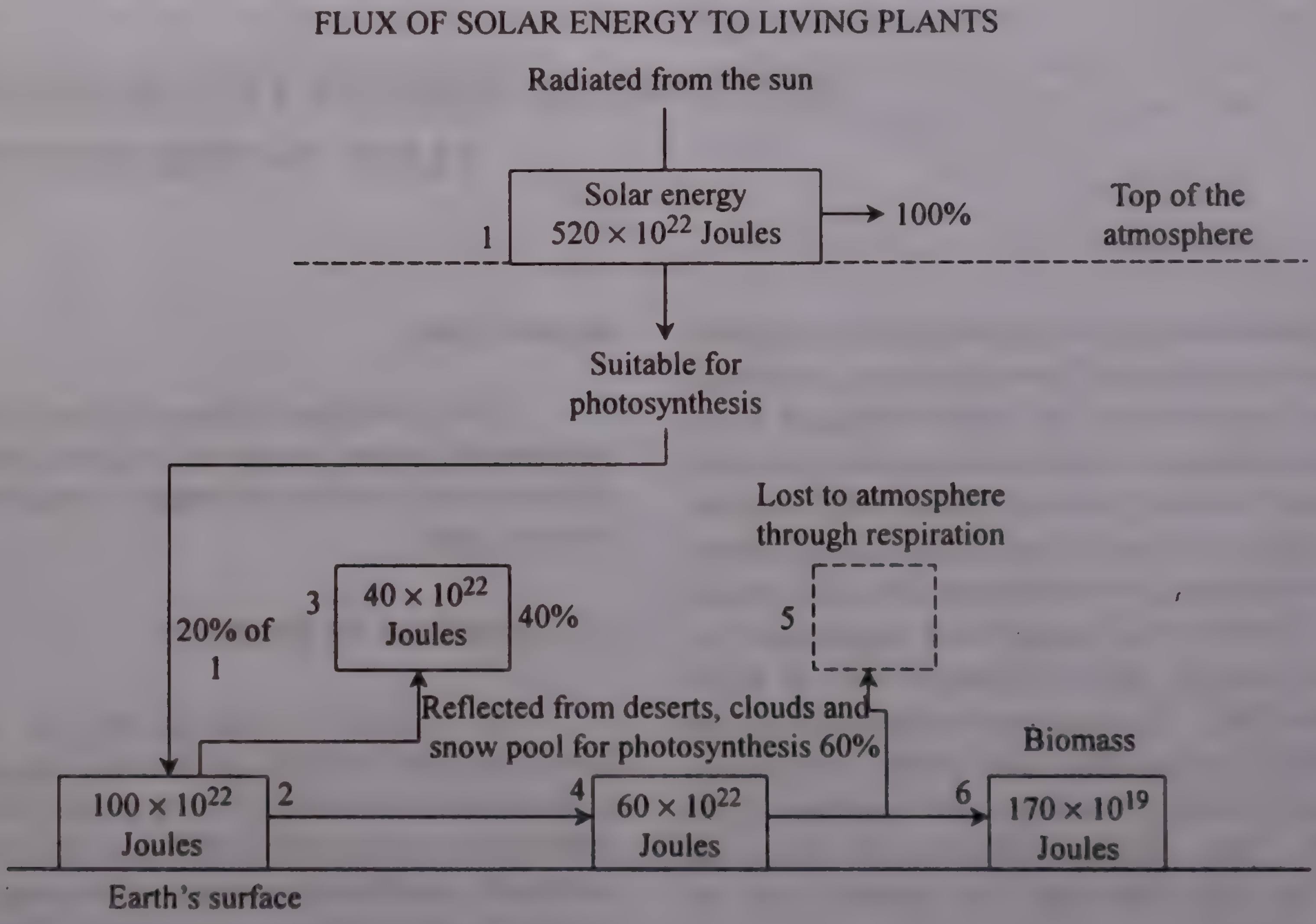

FLUX OF SOLAR ENERGY TO LIVING PLANTS
Radiated from the sun
Solar energy 520 × 10^22 Joules
1
100%
Top of the atmosphere
Suitable for photosynthesis
20% of 1
3
40 × 10^22 Joules
40%
Lost to atmosphere through respiration
5
Reflected from deserts, clouds and snow pool for photosynthesis 60%
Biomass
100 × 10^22 Joules
2
4
60 × 10^22 Joules
6
170 × 10^19 Joules
Earth's surface

Fig. 8.1 : The flow or flux of solar energy to living plants (Based on Ian Simmons, 1982).

The solar or light energy is transformed into food or chemical energy by the processes of **photosynthesis** by green plants. Some part of this chemical energy is lost to the atmosphere through respiration by the plants and the remaining part is stored in the plants as biomass. The energy is further transferred from one level of organisms to the other level of organisms and it is also used and spent at various levels of organisms. Thus the **flow of energy is unidirectional** and once used and spent is never available for reuse. "Energy is constantly flowing into the biosphere, undergoing various transformations which may involve being stored but ultimately being lost in the form of heat" (P.A. Furley and W.W. Newey, 1983). It is, therefore, necessary to discuss the transformation of solar energy into various forms before describing the mechanism of flow pattern of energy in the biospheric ecosystem.

8.2 ECOLOGICAL PRODUCTION

The solar energy or the sunlight is received and trapped by the green plants in the biosphere. The green plants contain pigment chlorophyll through which they convert solar energy into organic molecules (molecules having carbon). Infact, green plants use light energy to convert carbon dioxide and water into carbohydrates and other biochemical molecules. This process of conversion of light energy into food or chemical energy is called **photosynthesis.** The organisms which produce their own food are called **primary producers.** They are also known as **autotrophs.**

Primary producers fall in two categories e.g. (i) **phototrophs,** and (ii) **chemotrophs.** Phototrophs are those primary producers (green plants) which trap solar energy (light energy) and produce their own food through the process of photosynthesis. The chemotrophic primary producers are primarily chemosynthetic bacteria which produce their food energy through chemical processes wherein simple organic compounds are oxidised to obtain food energy. In other words, chemotrophs use already photosynthesised organic matter which is already present in the biosphere to produce their own food. The primary producers include chlorophyll containing green plants, green purple bacteria, blue green algae and phytoplanktons.

The total accumulated amount of energy stored by the autotrophic primary producers per unit area per unit time is called **ecological productivity.** In fact, the productivity of ecosystem refers to the rate of growth of energy or organic matter per unit time by autotrophic primary producers through the process of photosynthesis with the help of solar energy (light energy). The production of organic matter or energy by autotrophic primary producers is called **primary production** and the green plants involved in the production activity are called **primary producers.**

The productivity of the ecosystem depends on two factors e.g. (1) the availability of the amount of solar radiation to the autotrophic primary producers, and (ii) the efficiency of the plants to convert solar energy (light energy) into chemical energy (food energy) which is used by green plants to build up their tissues. Primary production/productivity is measured in two ways e.g. (i) **gross primary production** (GPP), and (ii) **net primary production** (NPP). Gross primary production is the total amount of energy produced by the autotrophic primary producers at tropic level one. In other words, gross primary production refers to total amount of energy assimilated by autotrophic primary producer green plants. Net primary production (NPP) represents the amount of energy or organic matter fixed or stored at trophic level one. Thus net primary production excludes the amount of energy which is lost through respiration by autotrophic primary producer plants. Net primary production is, thus, gross primary production minus the energy lost through respiration. Net primary production represents the usable amount of energy at trophic level one, which is made available to higher trophic levels. The ecosystem productivity whether, gross or net, is generally measured in gram/m^2/day or year.

Biomass refers to the quantity or weight of living matter per unit area per unit time and is represented in terms of dry weight. Biomass is comprised of plants and animals and therefore it is referred to as **plant biomass** or **animal biomass. Total plant biomass** including both above ground and subsurface plants is called **standing crop.**

It is necessary to draw a distinction between productivity and production. Productivity refers to the rate of increase of biomass whereas production is an amount of biomass of a given unit area at a given time.

Plant and animal biomass may be measured and represented separately. R.H. Whitaker and G.M., Woodwell (1971) have measured the net primary productivity, world net primary production and biomass of plants of major natural ecosystems of the whole earth's surface. Mean net primary productivity for the whole earth is 320 dry grams/

m^2/year whereas the mean values for the tropical rainforest, swamps and marshes and estuaries are 2000 dry grams/m^2/year in each case. Very low net primary productivity is of extreme desert, rock and ice (3 dry grams/m^2/year), desert scrub (70 dry gram m^2/year), open ocean (125 dry grams/m^2/year) and Tundra and Alpine ecosystems (140 dry grams/m^2/year). Table 8.1 presents the generalized picture of net primary production and plant biomass of the major natural ecosystems.

Table 8.1 : Net Primary Production and Plant Biomass.

Ecosystems	Mean net primary productivity (dry gram/m^2/year)	World net primary production (10^9dry tons)	Plant biomass (dry kg/m^2) (mean)	World plant biomass (10^9 dry tons)
1. Lake & stream	500	1.0	0.02	0.04
2. Swamp & Marsh	2000	4.0	12.00	24.00
3. Tropical forest	2000	40.0	45.00	900.00
4. Temperate forest	1300	23.4	30.00	540.00
5. Boreal forest	800	9.6	20.00	240.00
6. Woodland & shrub	600	4.2	6.00	42.00
7. Tropical Savanna	700	10.5	4.00	60.00
8. Temperate grassland	500	4.5	1.50	14.00
9. Tundra and Alpine	140	1.1	0.60	5.00
10. Desert scrub	70	1.3	0.70	13.00
11. Extreme desert, rock and ice	03	0.07	0.02	0.50
12. Agricultural land	650	2.10	1.00	14.00
Total land	730	109.00	12.50	1852.00
13. Open ocean	125	41.50	0.003	1.00
14. Continental shelf	350	9.50	0.01	0.30
15. Attached algae and estuaries	2000	4.00	1.00	2.00
Total ocean	155	55.00	0.009	3.30
Total for earth	320	164.00	3.6	1855.00

I.G. Simmons (1974) has estimated the net primary productivity for major world biomass (table 8.2). The mean net productivity of the whole world is 303 gram/m^2/year whereas total net productivity of the whole area of the world is 155.2×10^9 tonnes per year. Mean net primary productivity of the continental and oceanic ecosystems is 699 and 155 gram/m^2/year. It is obvious that mean net primary productivity of the continental ecosystems is about 4 times greater than the oceanic (marine) ecosystems. But the total net productivity of the whole area of the continental ecosystems (102.2× 10^9 tonnes per year) is only double of the marine (oceanic) ecosystems (55.0 × 10^9 tonnes per year) inspite of the fact that the oceanic ecosytems cover about 71 percent of the total area of the globe.

Table 8.2 : Estimated Net Primary Productivity of Major World Biomass

Vegetation Unit	Mean Productivity (g/m^2/year)	Total of net productivily (10^9 tonnes/year)
1. Forests	1290	64.5
2. Woodlands	600	4.2
3. Tundra	140	1.1
4. Desert scrub	70	1.3
5. Grassland	600	15.0
6. Desert	3	
7. Cultivated land	650	9.1
8. Fresh water	1250	5.0
9. Reefs and estuaries	2000	4.0
10. Continental shelf	350	9.3
11. Open ocean	125	41.5
12. Upwelling zones	500	0.2
Total continental	669	100.2
Total Oceanic	155	55.0
World Total	303	155.2

Source : I.G. Simmons, 1974

Since the primary productivity of a natural ecosystem largely depends on the amount of available solar radiation, there is positive correlation between primary productivity and solar radiation. Since there is marked decrease in solar radiation received at the earth's surface from equator towards the poles, primary productivity also, on an average (besides a few intermediate zones of exeception) decreases markedly towards the poles. This results in spatial variations in primary productivity at global, regional and local sçales. E.P. Odum (1959) has identified three levels of primary productivity of terrestrial ecosystems at world scale (fig. 8.2) as follows :

- the regions of high ecological productivity represented by shallow water areas, moist forests (tropical and temperate), alluvial plains and regions of intensive farming;
- the regions of low ecological productivity represented by arctic snow covered wastelands, and
- intermediate ecological productivity e.g. grasslands, shallow lakes and farmlands except intensively cultivated areas.

Though the productivity of ecosystem largely depends on the availability of required amount of solar radiation (sunlight) and the efficiency of plants to use this energy, there are also other factors which affect and control the ecosystem productivity e.g. **abiotic factors** (temperature, water quantity and depth of water, and above all climate and chemical factors-nutrient supply) and **biological factors** (mode of interactions between various populations such as mutualism, parasitism, predation etc. and internal instinctive control mechanisms within the populations such as social organization, territoriality and social hierarchies). When the aforesaid factors are favourable, there is quite high relative level of productivity. When one or more factors are in short supply or are not favourable to ideal ecosystem productivity ecological productivity becomes low. Such factor, which inhibits ecosystem productivity and therefore ecological production, is called **limitting factor.** For example, water is a limiting factor in the hot desert areas because sufficient vegetation cannot develop due to scarcity of water though sunlight, temperature

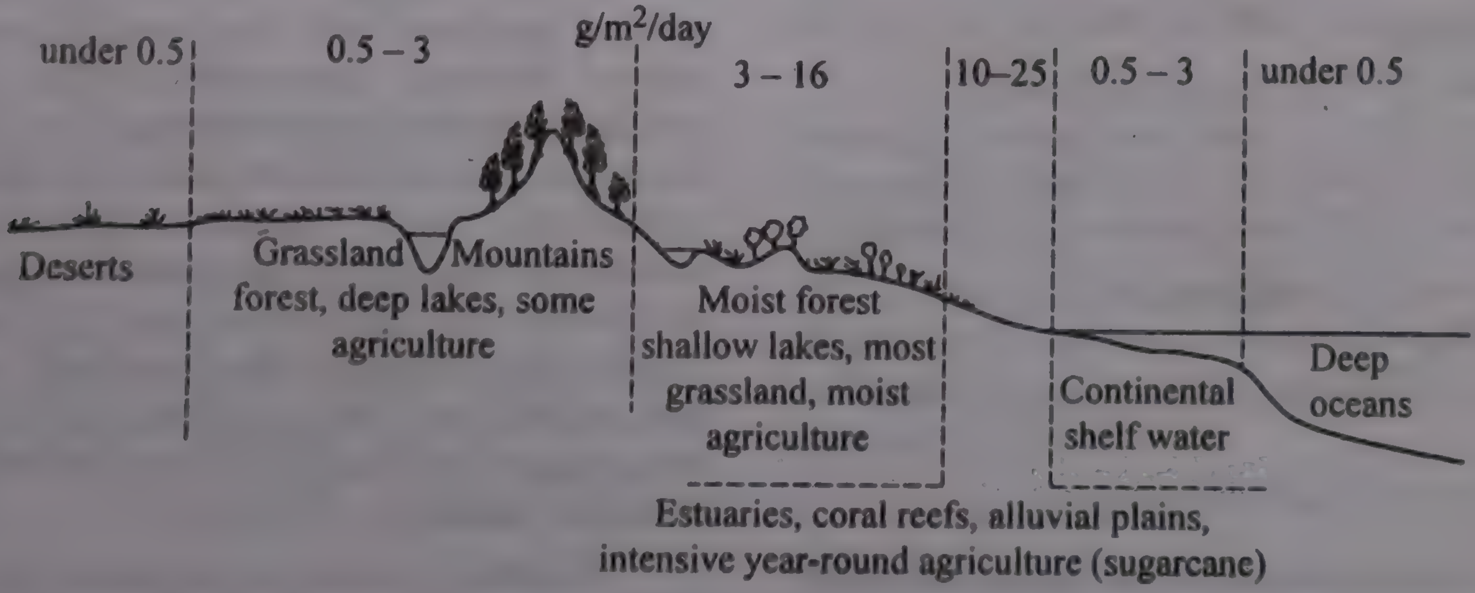

under 0.5
0.5 – 3
g/m^2/day
3 – 16
10–25
0.5 – 3
under 0.5
Deserts
Grassland
Mountains
forest, deep lakes, some agriculture
Moist forest
shallow lakes, most grassland, moist agriculture
Continental shelf water
Deep oceans
Estuaries, coral reefs, alluvial plains, intensive year-round agriculture (sugarcane)

Fig. 8.2 : World distribution of primary productivity of the major world ecosystems (after E.P. Odum, 1963, 1971). The units are grams of dry organic matter/m^2/day.

and nutrients are plentiful. Similarly, sunlight and temperature are limiting factors in polar areas.

It is important to note that there is also variation in the rate and amount of photosynthesis with the season (more photosynthesis and hence more gross primary production during summer season than winter season of a year) and with the age of the plant, animal or microbe. In the initial stages of the development of living organisms **gross primary production** (GPP) and **net primary production** (NPP) both increase but after the attainment of mature stage of biotic community there is increase in GPP but at slow rate, whereas NPP decreases because of increase in respiration due to greater consumption of energy in respiration.

The herbivorous animals depend on autotrophic primary producer plants for their food. Thus the herbivores build up their tissues through the food energy derived from autotrophic plants. These herbivorous animals are called **primary consumers.** The total amount of matter or energy assimilated by herbivorous animals is called **secondary production.** The **gross secondary production** (GSP) represents the amount of energy assimilated and accumulated by heterotrophs whereas the **net secondary production** includes the amount of energy or organic matter assimilated and accumulated by heterotrophs minus energy lost through respiration. The **net community production** (NCP) represents net secondary production by all heterotrophs at different trophic levels and unused primary production.

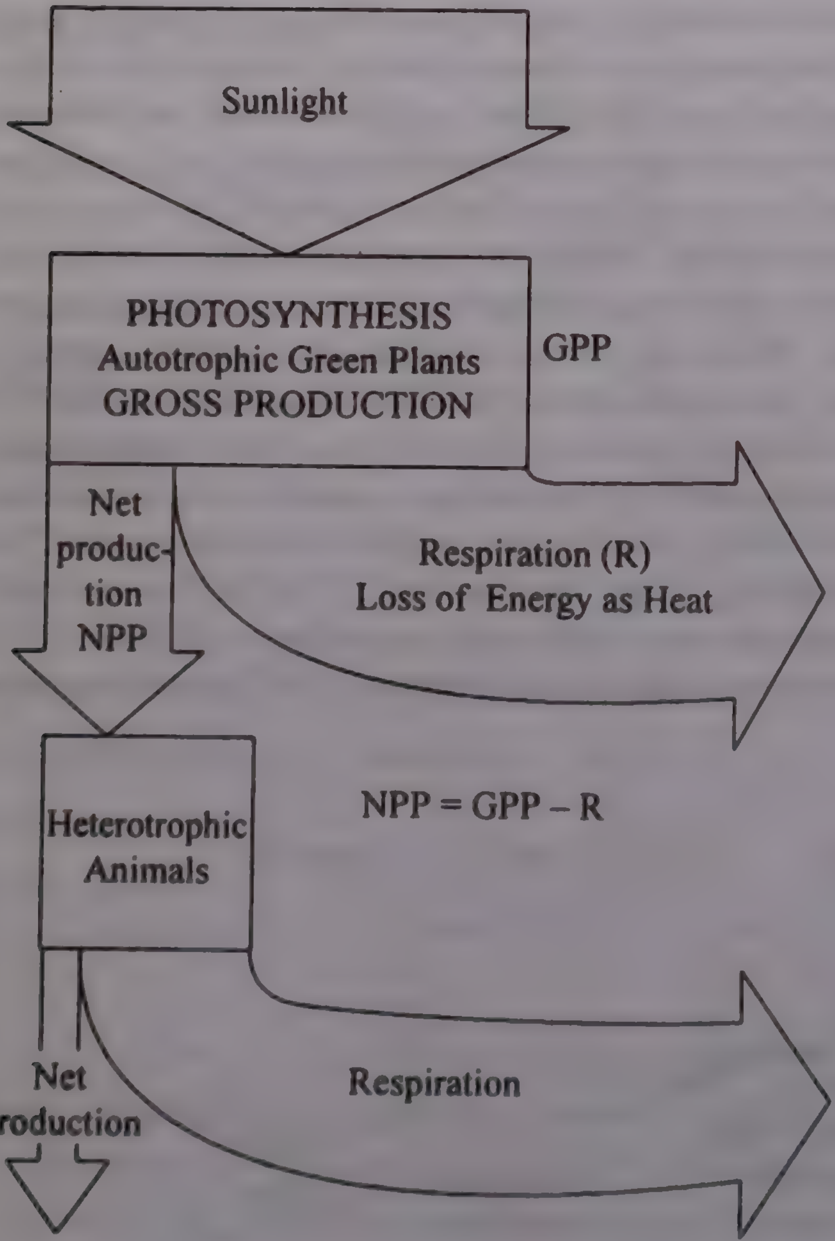


Fig. 8.3 : Ecological production and energy flow (modified from D.B. Botkin and E.A. Kellar, 1982). NPP = Net Primary Production; GPP = Gross Primary Producton.

8.3 TROPHIC LEVELS, FOOD CHAINS AND FOOD WEBS

As stated earlier, green plants are very important biotic component of the biospheric ecosystem because these green plants manufacture their own food which becomes source of food energy for all types of organisms in the biosphere. Plants manufacture their food with the help of carbon dioxide, inorganic salt (phosphorous and nitrates), water and sunlight. Carbon dioxide is taken by plants from the atmosphere through their leaves during day time while inorganic salts and water are taken by plants from the soils through their roots by the process of **root osmosis.** The green pigment chlorophyll of plants traps solar radiation or sunlight. Now plants convert water and carbon dioxide into starch and sugar with the help of sunlight. The whole chain of this process is called **photosynthesis.** Thus the green plants are called **primary producers** and the animals depending on primary producer plants (autotrophs) are called **consumers (heterotrophs).** Some animals exclusively depend on other animals for their food whereas some animals (e.g. man) depend on both, plants and animals for their food. The animals deriving their food exclusively from plants are called **herbivores.** Those animals, which take their food exclusively from animals, are called **carnivores** and the animals depeding on both, plants and animals, for their food are called **omnivores** (e.g.man).

Feeding (or transfer and assimilation of food energy) takes place in hierarchical order in the ecosystem through various levels. Thus the levels through which food energy passes from one group of organisms to the other group are called **trophic levels.** The chain of transformation and transfer of food energy in the ecosystem from one group of organisms to the other group through a series of steps or levels (trophic levels) is called **food chain.** In other words, the chain of transfer of food energy from one group of organisms to the other group in the biosphere (ecosystem) is called **food chain** and the point where food energy is transferred from one group of organisms to the other group is called **trophic level.** The concept of trophic level is based on the classic work of R.L. Lindman (1942) who pointed out "that living organisms can be grouped into a series of more or less discrete trophic levels with each level depending on preceding one for its energy (food) supply". On an average four trophic levels of a food chain are identified.

(1) **Trophic level 1 :** The base of the food chain is formed by autotrophic primary producer organisms which include green plants. This base of the food chain is called trophic level 1 where green plants produce their food through the process of photosynthesis with the help of sunlight, water, carbon dioxide and inorganic salts and they consume the produced energy to build their tissues and bodies. The trophic level 1 is also the source of food for all other organisms of the food chain. All the green plants are the members of trophic level 1.

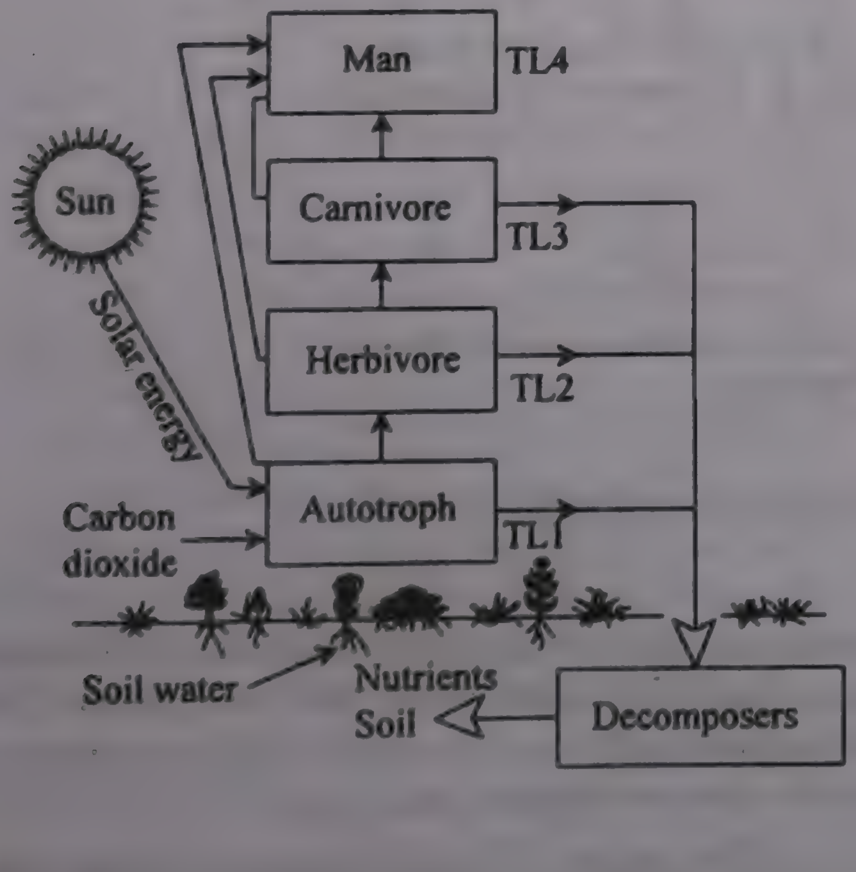


Fig. 8.4 : Functional relationships between different trophic levels in an ecosystem.

(2) **Trophic level 2 :** The organisms, who do not produce their food themselves but depend on primary producers (of trophic level 1) for their food, are included in trophic level 2. These organisms are animals and are called **primary consumers.** They are basically grazers like sheep, cows, rabbits, goats, deers etc. These animals are also called **herbivores.** The trophic level where food energy is transferred from primary producers to primary consumers is called trophic level 2 (fig. 8.4 and 8.5).

(3) **Trophic level 3 :** The animals, who depend on animals mainly herbivorous animals for their food, are included in this trophic level. These animals are called **carnivores** and **secondary consumers** because they depend on the primary consumer animals of herbivorous group of trophic level 2. Carnivores include (I) land animals-lions, hawks, beers, leopard, eagles etc,; (II) animals living in the soils-bacteria which decompose dead herbivorous animals; (III) aquatic animals-herring. The trophic level where energy is transferred from primary consumers to secondary consumers is called trophic level 3 (figs. 8.4 and 8.5).

(4) **Trophic level 4 :** Those animals are included in this trophic level which take their food either directly or indirectly from all the three lower trophic levels. Man is the most important member of this trophic level because he derives food and fuel from the green plants, commodities from second and third trophic levels. Such animals (as man) are called **omnivores.** Decomposers also derive their energy from all the trophic levels (fig. 8.4).

A **food chain** is in fact the sequence of energy transfer from the lower trophic levels to the upper or higher trophic levels. A simple linear food chain may be illustrated by the following example (fig. 8.5).

1. Plants (primary producers)→herbivorous animals (primary consumers)→carnivorous animals (secondary consumers or primary carnivores)→ carnivores/omnivores (secondary carnivores).

2. Grass (primary producer) is eaten by→sheep (herebivores, primary consumer)→sheep is eaten by→wolves (carnivores, secondary consumer or primary carnivore).

3. Grass→insects→frogs→snake→hawk→ leopard.

When the feeding relationships in a natural ecosystem become more complicated, the food chain does not remain simple and linear rather it is

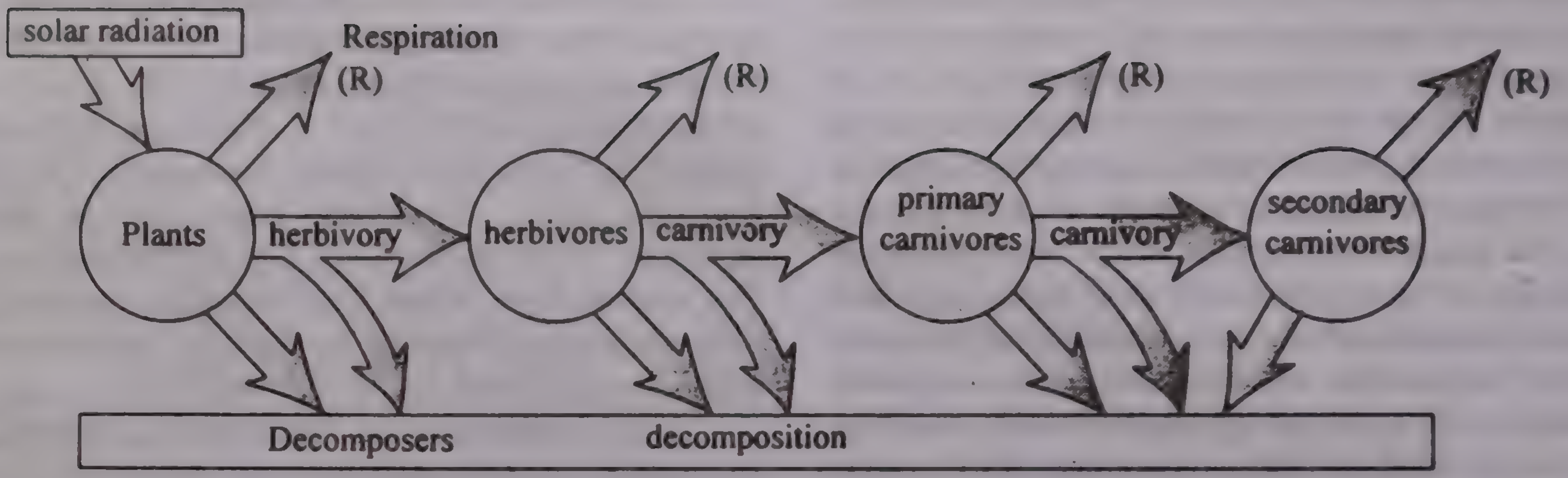

solar radiation
Respiration
(R)
(R)
(R)
(R)
Plants
herbivory
herbivores
carnivory
primary carnivores
carnivory
secondary carnivores
Decomposers
decomposition

Fig 8.5 : A simple linear food chain and energy flow.

also complicated by several inter-connected overlapping food chains. This happens when greater number of species feed on many kinds of prey. Such complicated food chain is called **food web.** For example, there are various pathways of transfer of energy between diatoms (primary producer in marine ecosystem) and adult herring (fig. 8.6) e.g. (i) herring feeds on arrow worms which feed on barracle larva which feeds on diatoms; (ii) herring feeds on sea butterfly which feeds on pseudo calanus, acortia, temora, calanus, all of which feed on diatoms, and so on.

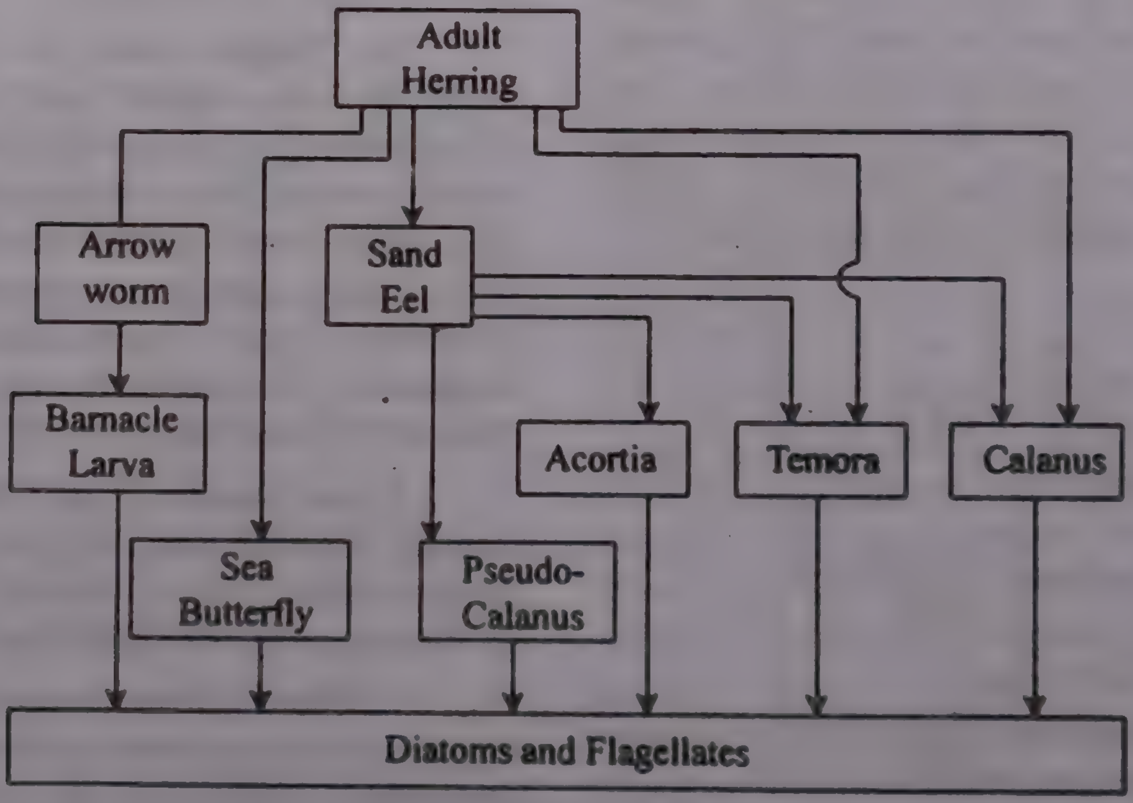

Adult Herring
Arrow worm
Sand Eel
Barnacle Larva
Acortia
Temora
Calanus
Sea Butterfly
Pseudo-Calanus
Diatoms and Flagellates

Fig.8.6 : Illustration of a marine food web (based on J. Phillipson, 1966).

Figure 8.7 illustrates another example of complicated food web in a polar (arctic) ecosystem where there are several inter-connected food chains. e.g. (i) Man eats caribou which feeds on grasses; (ii) Man feeds on whales which eat crustacea which feed on diatoms; (iii) Man eats walrus which eats crustacea which feed on diatoms; (iv) Wolf eats caribou and hares which feed on grasses; (v) Fox eats lemmings and hares which feed on grasses; (vi) Polar bear feeds on fish which feeds on crustacea which feed on diatoms and so on.

The nature of food chains and food webs depends on the richness or poorness of biodiversity of a natural ecosystem. The richer the biodiversity, the longer and more complicated the food chains and food webs. The ecosystem stability also depends on biodiversity and food chains and food webs. As the biodiversity increases, the food chains and food webs become longer and more complicated, so the ecosystem becomes more stable. A simpler food chain represents unstable ecosystem and poor biodiversity.

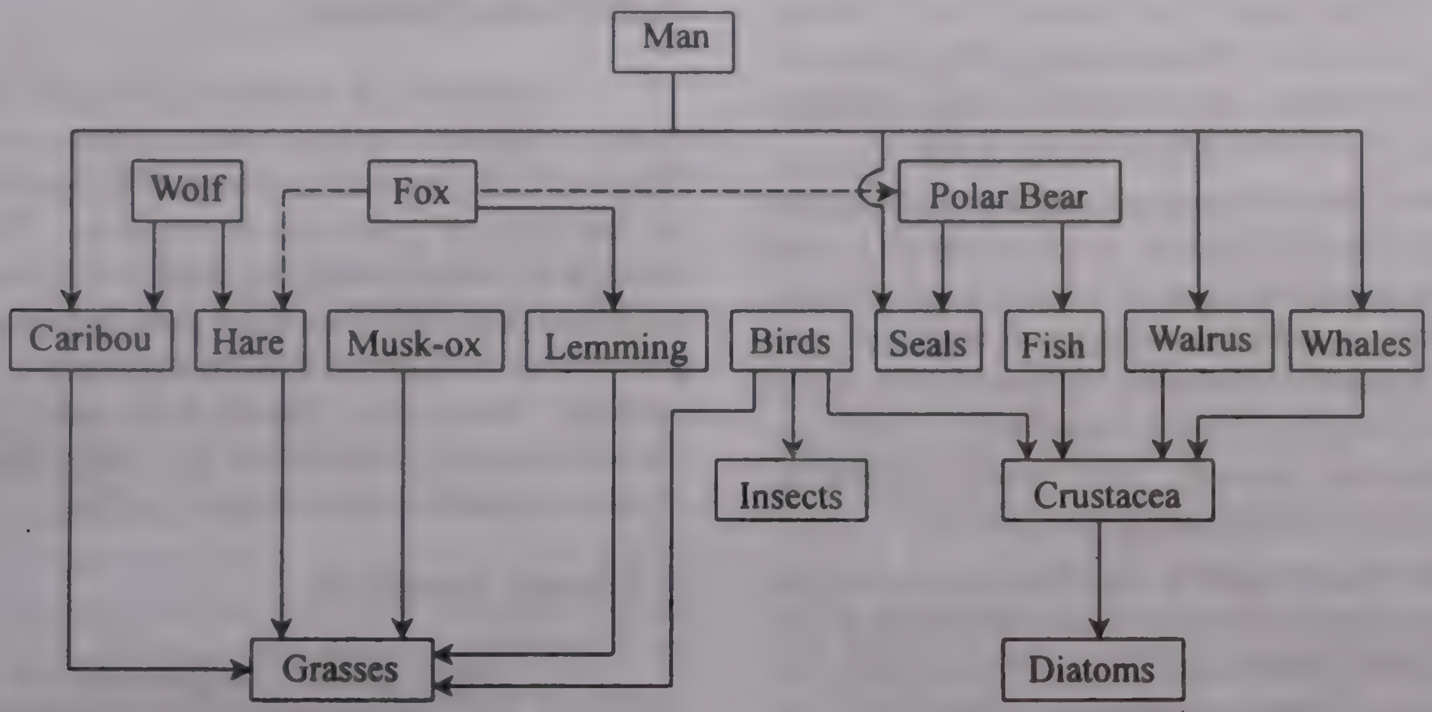


Fig. 8.7 : Illustration of a complicated polar (arctic) foodweb (based on J. Phillipson, 1966).

8.4 ECOLOGICAL PYRAMIDS

If we look into the nature and pathways of transfer of energy through different trophic stages (levels) and total biomass at each trophic level we find certain common characteristics e.g. (i) The number of species tends to decline successively from the base of the trophic level (trophic level 1) to the top of the trophic level. (ii) The total biomass tends to decrease progressively from the base of the trophic level through successive higher trophic levels to the top. (iii) The energy availability at each successive higher trophic level decreases. Thus, it is obvious that the number of species, the total biomass and energy availability decrease with successive higher trophic levels in the food chain in such a way that the shape becomes like a pyramid. This is called **ecological pyramid.** There are three types of ecological pyramids e.g. (i) the pyramids of numbers, (ii) biomass pyramid, and (iii) energy pyramid.

1. Number Pyramids

Number pyramids include only the number of species and not their sizes (whether the organisms have larger bodies or smaller ones). C. Elton (1927) has pointed out that "the animals at the base of a food chain are relatively abundant, whilst those at the end are relatively few in number, and there is a progressive decrease in between the two extremes". Thus, the pyramid of number means progressive decrease in the number of species with successive higher trophic levels. On an average the primary producers or the autotrophic green plants are small in size but very large in number at the base of the pyramid (representing trophic level 1) because these have to provide food to the animals of trophic level 2 which are smaller in number (than the plants at trophic level 1) but larger in size. Similarly, the number of animals at trophic level 3 is smaller than the number of animals at trophic level 2 but the size of animals becomes larger at trophic level 3 than at trophic level 2 and so on. For example, if a cow (primary consumer at trophic level 2) feeds on grass (primary producer at trophic level 1), there must be numerous blades of grass to feed and support one cow (figure 8.8A).

In the forest ecosystem the situation is reversed because the primary producers (trees) are very large in size at the base of trophic level (trophic level 1). In such cases a single large tree is capable of supporting a large number of primary consumer animals (herbivores) at trophic level 2, with the result the pyramid of number becomes tapering at the base of trophic levels (due to small number of plants) and most extensive at trophic level 2 (due to large number of herbivorous animals) but thereafter the pyramid assumes its normal shape (narrow upward). This is evident from figure 8.8B.

If a food chain represents primary producers of very large size (trees) at trophic level 1, and parasites and hyperparasites at trophic levels 2 and 3 as primary and secondary consumers respectively, the resultant pyramid is **inverted pyramid** (fig. 8.8C) because one single primary producer (tree) can support numerous primary consumers (parasites) and secondary consumers (hyperparasites).

Though the pyramids of number of species help in the comprative study of the diversity of the structure and food chains and food webs of different ecosystems (e.g. forest ecosystem, marine ecosystem, river ecosystem, lake ecosystem etc.) but these do not give any idea about the total biomass (total weight of living organisms) because pyramids of number consider only the number of organisms and not the size of the organisms.

2. Biomass Pyramid

Pyramids of biomass include the biomass (total weight of organic matter) of each trophic level (figure 8.8D) instead of number of species as is done in the case of pyramid of numbers. Thus the total weight of whole organic matter (biomass) at each trophic level represents the **standing crop** at a single point in time. This enables the pyramid to assume its natural shape i.e. broad base and thin appex. Biomass pyramid does not give any idea of the rate of ecological/ecosystem production.

3. Energy Pyramids

C. Elton (1927) suggested to construct a pyramid of energy to have an idea of ecological

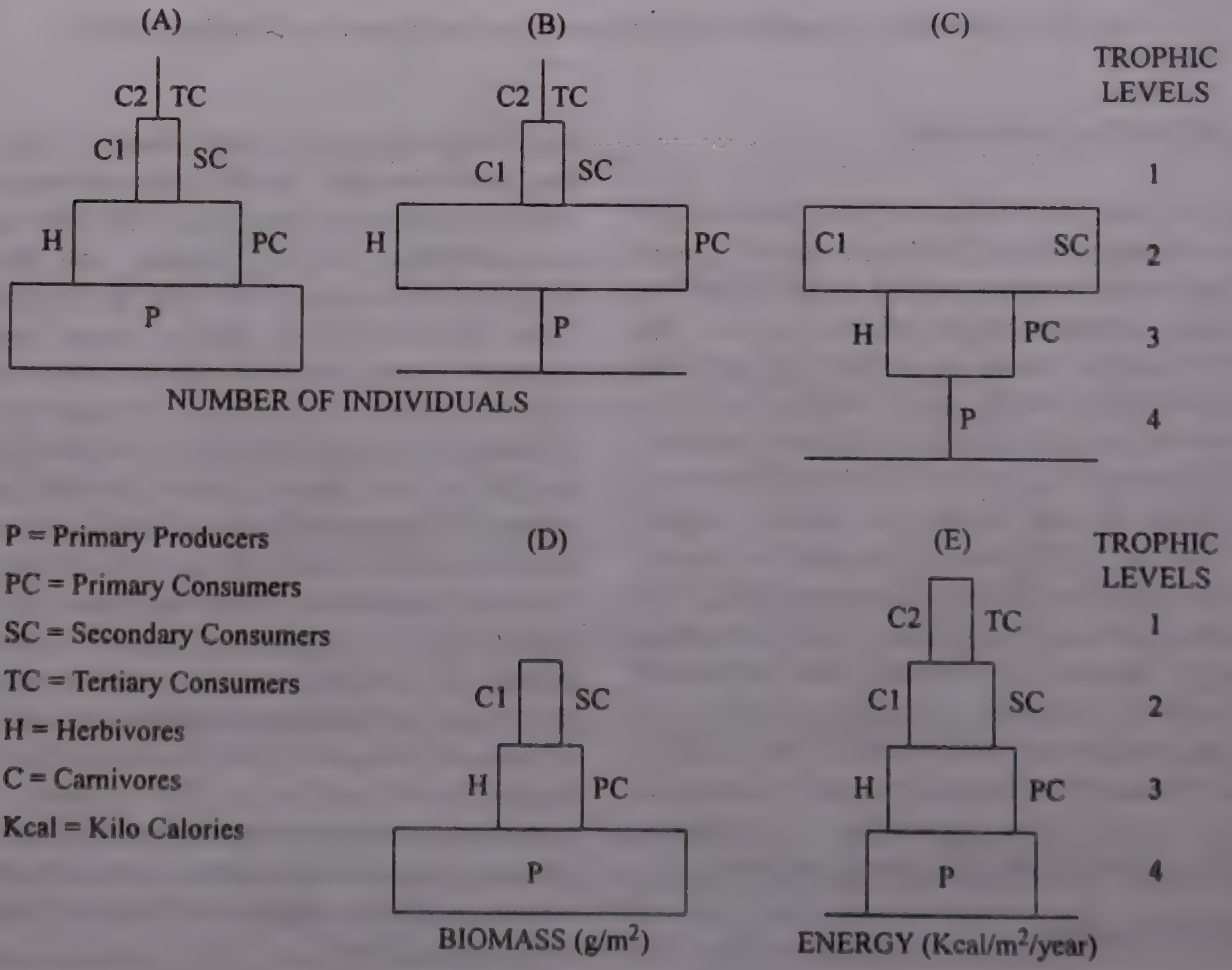

(A)
C2
TC
C1
SC
H
PC
P
(B)
C2
TC
C1
SC
H
PC
P
NUMBER OF INDIVIDUALS
(C)
TROPHIC LEVELS
1
C1
SC
2
H
PC
3
P
4
P = Primary Producers
PC = Primary Consumers
SC = Secondary Consumers
TC = Tertiary Consumers
H = Herbivores
C = Carnivores
Kcal = Kilo Calories
(D)
C1
SC
H
PC
P
BIOMASS (g/m²)
(E)
TROPHIC LEVELS
C2
TC
1
C1
SC
2
H
PC
3
P
4
ENERGY (Kcal/m²/year)

Fig. 8.8 : Ecological pyramids -(A) pyramid of numbers, (B) pyramid of numbers with large tree at the ground, (C) inverted pyramid, (D) biomass pyramid and (E) energy pyramid.

productivity. The energy pyramid is constructed, thus, on the basis of total amount of energy used at each trophic level per unit area per unit time. The total amount of energy used is generally expressed in kilocalories (Kcal) per square metre per day or per year (Kcal/m^2/year). Energy pyramids help in the comparative study of the productivities of different ecosystems (fig. 8.8 E).

8.5 ENERGY FLOW

Solar radiation is the basic input of energy which enters the ecosystem. This solar energy passes through the hierarchy of trophic levels in a food chain and food web and ultimately becomes output from the ecosystem as energy is lost through respiration from each trophic level. **Biosynthesis** is the process of the formation of organic tissue which represents the transformation of solar or light energy into chemical or food energy. **Biodergradation** is the process of breakdown and decomposition of organic matter and thus this process refers to the release of nutrients and food (chemical) energy in the form of heat. The energy flow (transfer of organic molecules) in the ecosystem is unidirectional and is non-cyclic (is not available again for reuse).

The radiant solar energy or light (of the sun) energy is trapped by green plants (primary producers or autotrophs) and is used to prepare food (chemical organic matter) through the process of photosynthesis. Thus autotrophic (or phototrophic) green plants transform a part of solar energy into food or chemical energy which is used by the green plants (primary producers at trophic level 1) to develop their tissues and thus it is stored in the primary producers or autotrophs at the bottom of trophic levels (i.e. trophic level 1).

The chemical energy stored at trophic level 1 becomes the source of energy either directly or indirectly to all of the animals at different trophic levels in a food chain in a natural ecosystem. Some portion of energy is lost through respiration from trophic level 1 and some portion of chemical energy is transferred to plant-eating animals (herbivores) at trophic level 2. Some portion of plants falls down without being consumed by herbivores of trophic level 2 on the ground surface and is ultimately consumed by detrivores or decomposers and thus some energy is also transferred from trophic level 1 to the decomposers living in the soils. It may be pointed out that the transfer of energy from trophic level 1 (green plants, primary producers or autotrophs) is performed through the intake of organic tissues (which contain potential chemical energy) of green plants by the herbivorous animals (when a cow grazes grasses, chemical energy stored in grasses is transferred to the cow).

Thus the chemical energy consumed by herbivorous animals (derived from trophic level 1 through food intake) helps in the building of their own tissues at trophic level 2 and thus the energy is stored in them. This stored energy in the bodies of herbivores now becomes the source of energy for carnivorous animals (secondary consumers) at trophic levle 3. A substantial portion of chemical energy is lost through respiration from herbivores at trophic level 2 because the animals have to consume energy for their movement for getting food from green plants. In other words, energy is required for the work to be done and when work is done energy is dissipated and the work is done when one form of energy is transformed into another form (second law of thermodynamics). Some portion of potential chemical energy is transferred to carnivorous animals at trophic level 3 through intake of food from herbivores. Some portion of energy is released by herbivores as wastes (e.g. dung, urine etc.) which are decomposed by detrivores or decomposers. Still some portions of herbivores, when dead, are broken down and decomposed by decomposers (fig. 8.9).

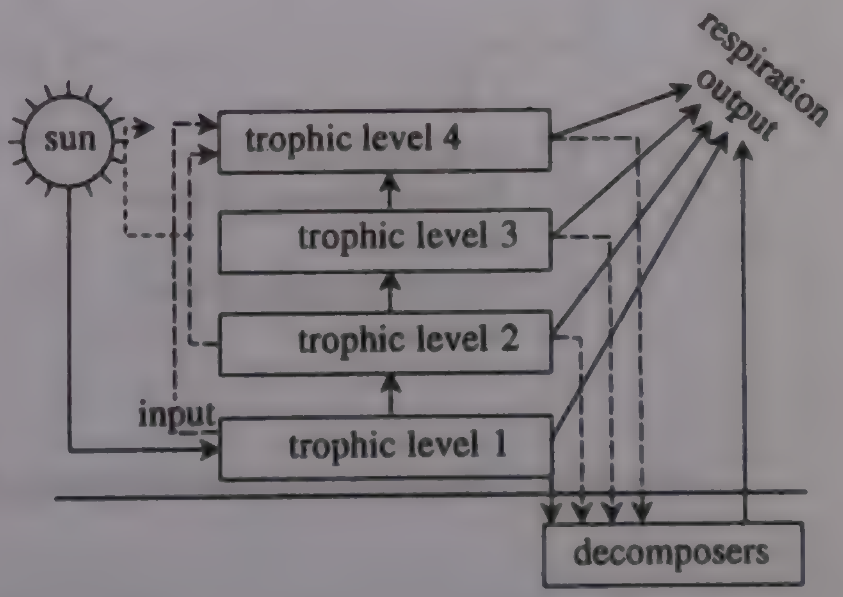


Fig. 8.9 Generalized pattern of energy flow in an ecosystem. Solid liines indicate major pathways and dashed lines indicate minor pathways of energy flow.

A substantial portion of potential chemical energy stored in the bodies of carnivores is lost through respiration from trophic level 3 because the carnivorous animals have to run for greater distances to catch their preys. A portion of chemical energy is transferred to trophic level 4 or tophic level represented by ominivores (those animals which eat both plants and animals, man is the most important example of omnivores). The animals at trophic level 4, mainly man, also take energy from trophic levels 1 and 2 (fig. 8.9). Again some portion of energy is released through respiration from trophic level 4 by omnivores. The omnivores, after their death, are decomposed by the decomposers.

Thus it is obvious from the above discussion and figs, 8.9 and 8.10 that there are three-way pathways of flow of energy in the natural ecosystem as follows :

(i) transfer of chemical energy from each trophic level to the next higher trophic level (i.e. from trophic level 1 to 2, from 2 to 3 and from 3 to 4) and direct transfer of chemical energy from trophic levels 1 and 2 to trophic level 4 (top trophic level);

(ii) transfer of chemical energy from dead organisms of each trophic level to decomposers, and

(iii) loss of energy in the form of heat through respiration from each trophic level and from decomposers (fig. 8.10). The whole amount of heat energy released from different organisms through respiration is lost to the atmosphere and thus is nct again available to the organisms for reuse. It is thus evident that the energy flow in the ecosystem is unidirectional and non-cyclic.

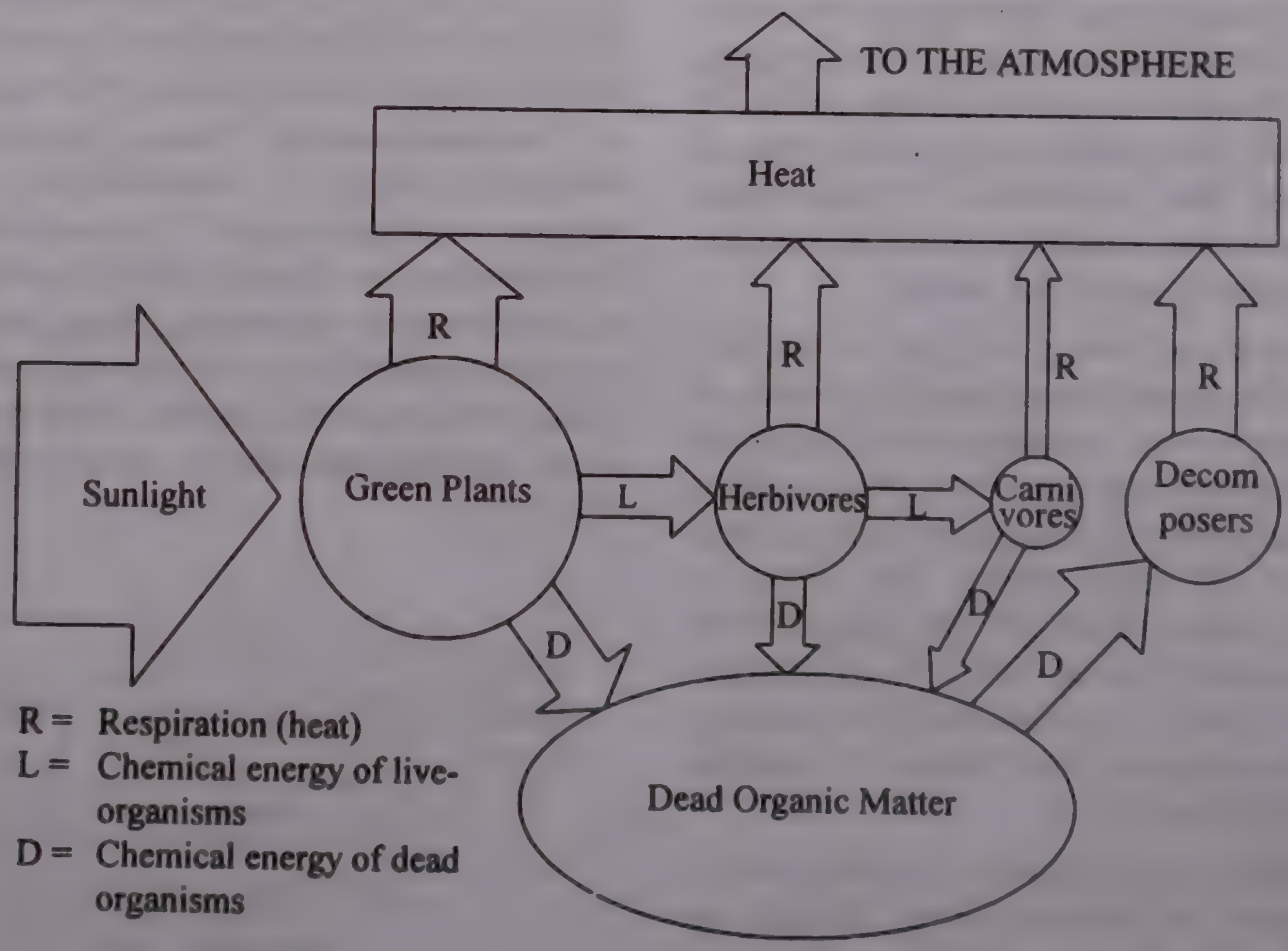


Fig. 8.10 : Simplified mechanism of energy flow in the ecosystem (based on H.J.M. Bowen, 1966).

The first law of thermodynamics, "that in any system of constant mass, energy is neither created nor destroyed but it can be transformed from one type to another type, the energy inflow or input in a system is balanced by energy outflow or output", holds good in the mechanism of energy flow in the ecosystem as elaborated above. Light energy (solar radiation) is transformed into chemical energy (food energy) by autotrophic green plants through the process of photosynthesis. The chemical energy is released as heat energy through respiration by the organisms at different trophic levels. R.L. Lindeman

(1942) has formulated the following five principles regarding the relationships betwen different trophic levels and energyflow in a natural ecosystem.

Principle I : As the distance between the organisms of a given trophic level and the initial source of energy (trophic level 1) increases, the probability of the organisms to depend exclusively on the preceding trophic level for energy decreases. In other words, the organisms at trophic levels 3 and 4 do not depend for their energy only on trophic levels 2 and 3 respectively rather they receive energy from more than one source (trophic level) which means that organisms at trophic level 3 and beyond tend to be 'generalists' rather than 'specialists' in terms of their feeding habit.

Principle II : The relative loss of energy due to respiration is progressively greater from higher trophic levels because the species at higher trophic levels being relatively larger in size have to move and work more for getting food and therefore more energy is lost due to respiration.

Principle III : Species at progressively higher trophic levels appear to be progressively more efficient in using their available food supply, because increased activity by predators increases their chances of encountering suitable prey species, and in general predators are less specific than their prey in food preferences'.

Principle IV : 'Higher trophic levels tend to be less discrete than the lower ones' because the organisms at progressively higher trophic levels receive energy from more than one source (trophic level) and are 'generalists' in their feeding habit and they are more efficient in using their available food supply.

Principle V : 'Food chains tend to be reasonably short. Four vertical links is a common maximum' because loss of energy is progressively higher for higher trophic levels and species at higher levels tend to be less discrete.

9

CIRCULATION OF MATTER IN THE ECOSYSTEM

9.1 NATURE OF MATTER

The circulation of elements (matter) or nutrients (both organic and inorganic) in the biospheric ecosystem is made possible through energy flow. In other words, energy flow is the main driving force of material (nutrients) circulation in the various biotic components of the ecosystem (the biosphere). The organic and inorganic substances are moved reversibly in the biosphere, atmosphere, hydrosphere and lithosphere through various closed system of cycles in such a way that the total mass of these substances remain almost the same and these substances are always available for use by the biotic communities. "In other words, the materials, that make up the biosphere are distributed and redistributed by means of an infinite series of cyclic pathways motored by the continuous input of energy" (P.A. Furley and W.W. Newey, 1983).

The materials or elements are also called nutrients because they help the organisms to build up their tissues and bodies. The chemical elements, which enter the ecosystem (the biosphere) through plants, are very important to biotic communities because they are essential for the sustenance of life in the biosphere. The elements come from two basic sources or reserviors viz. (1) lithosphere or the earth's crust (lithospheric source or reservoir), and (ii) atmosphere (atmospheric source or reservoir). When the chemical elements are involved in the growth and maintenance of organisms, these are called **mineral nutrients.**

The chemical elements or simply the materials or mineral nutrients (or simply nutrients) involved in the circulation within an ecosystem (the biosphere) and in the growth and maintenance of organisms are grouped into three categories e.g. (i) **Macro-elements,** which are required in large quantity by plants. These include oxygen, carbon and hydrogen which form the basic cell structures of the organisms and are the principal components of fats and carbohydrates in the organism. (ii) **Minor elements,** which are required by plants in relatively large amount. These elements include nitrogen, phosphorous, potassium, calcium, magnesium and sulphur. Nitrogen helps in the synthesis of proteins; phosphorous is responsible for the building of nucleic acids and cyptoplasm and the transfer of energy through cells of the organisms; sulphur helps in the formation of amino acids which form proteins; cell walls of the organisms are strengthered by calcium whereas chlorophyll is produced by magnesium. (iii) **Trace elements,** which are required by plants in very small quantity. There are about 100 elements which are required by plants but the elements which are most required by plants are iron, copper, manganese, zinc, boron, chlorine, molybdenum etc.

Besides chemical elements, there are also organic materials which are involved in the circulation of elements or nutrients in the biospheric ecosystem. The organic materials comprise (i) decomposed parts of either alive or dead plants and animals, and (ii) waste materials excreted (released) by animals (e.g. dung).

A few of the chemical elements act as organic catalysts or enzyems because they help chemical reactions but seldom undergo chemical changes themselves.

The elements (chemical or inorganic and organic) which are circulated in the biosphere belong to three main phases : (i) **atmospheric phase** (hydrogen, oxygen, carbon, nitrogen), (ii) **sedimentary phase** (potassium, calcium, magnesium, phosphorous, sulphur etc.), and (iii) **organic phase** (organic matter including both plants and animals).

9.2 BIOGEOCHEMICAL CYCLES

Biogeochemical cycles may also be termed as **geobiochemical cycles** because the necessary nutrients are provided by the soils and the roots of phototrophic green plants take the nutrients in solution form through the process of root osmosis from the soils. The biologists prefer to use the term **biogeochemical cycles** because plants play active role in the cyclic pathways of nutrients.

'A biogeochemical cycle is the cycling of chemical element' through the earth's atmosphere, oceans and sediments as it is affected by the geological and biological cycles. It can be described as a series of compartments or storage reservoirs, and pathways between these reservoirs' (D.B. Botkin and E.A. Keller, 1982). P.A. Furley and W.W. Newey (1983) have defined biogeochemical cycles as 'large scale cycles, involving inorganic substances which pass through a biotic phase and then return to an inorganic state'.

The elements derived from the atmospheric and sedimentary reservoirs are pooled into soils. The chemical or inorganic elements stored in sedimentary phase are made available to soil pool or reservoir due to weathering and erosion of rocks. The inorganic elements of the atmospehric phase are brought to the soils under the impact of precipitation. The inorganic elements or nutrients pooled in the soil reservoir are teken up by plants in solution form through the process of root osmosis. The plants then convert these inorganic elements into such forms which are easily used in the development of plant tissues and plant growth by biochemical processes (generally photosynthesis). Thus the nutrients driven by energy flow pass into various components of biotic communities through the process known as **biogeochemical cycles.**

In a generalized form the biogeochemical cycles include the uptake of nutrients or inorganic elements by plants through their roots in solution form from the soils where these inorganic elements, derived from **sedimentary phase,** are stored (fig. 9.1). Some nutrients are leached from the soil pool and are brought back to the sedimentary phase while some nutrients (chemical or inorganic matter) are washed out and are brought to the ocean by rivers (fig. 9.1). The inorganic elements or nutrients taken up by plants are transported to various trophic levels along the food chain through energy flow (fig. 9.2).

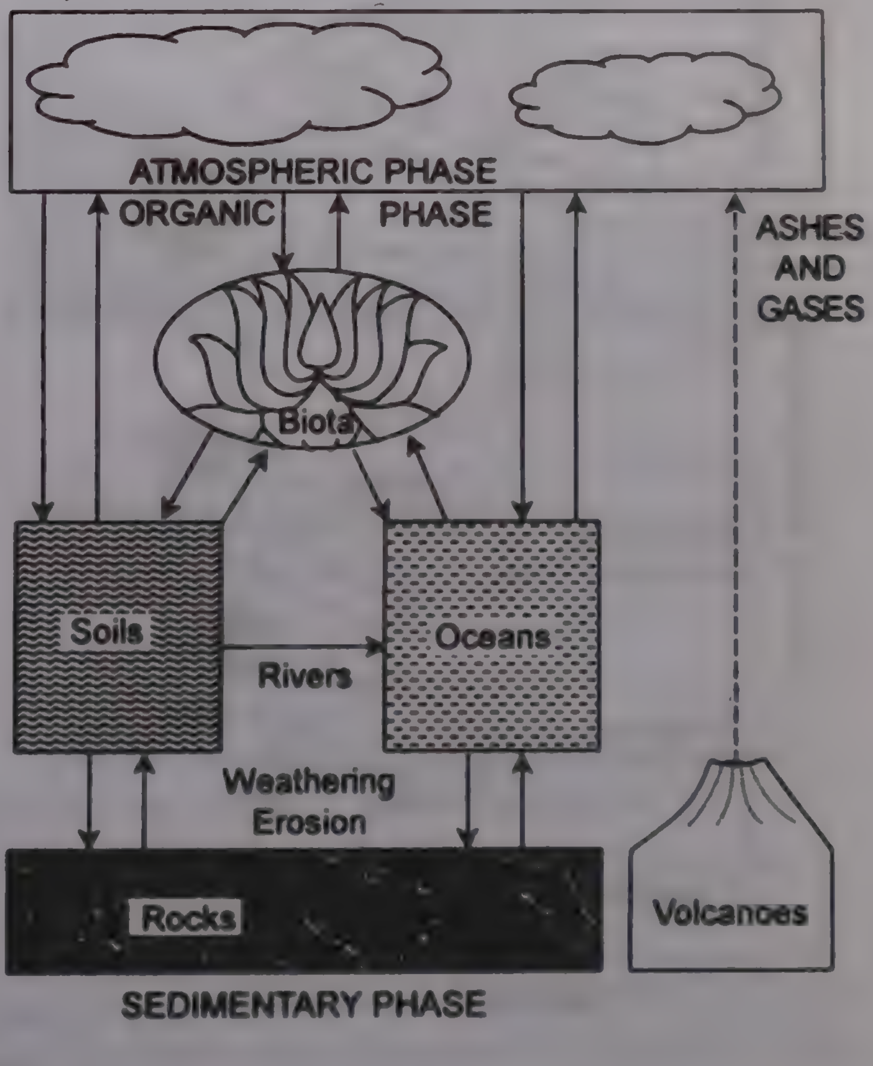


Fig. 9.1 : Generalised and simplified biogeochemical cycle (based on D.B. Botkin and E.A. Keller, 1982).

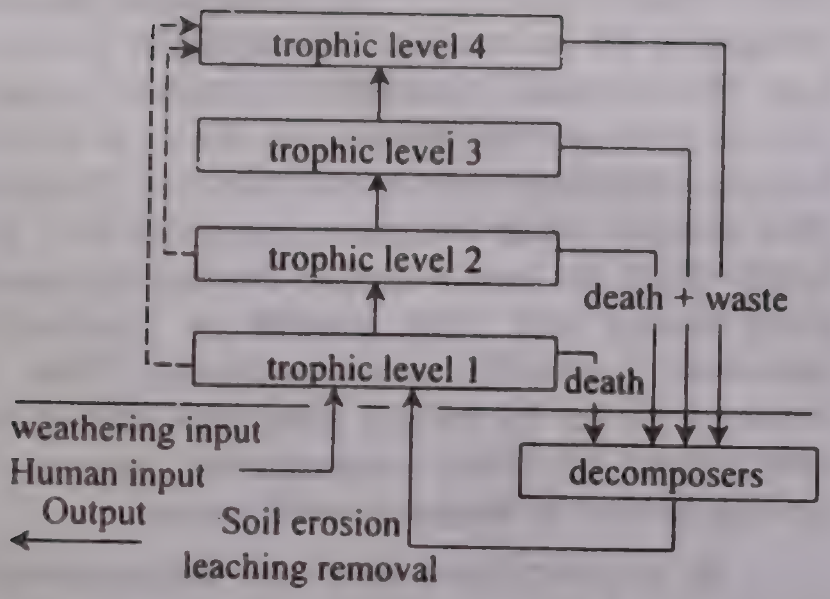

trophic level 4
trophic level 3
trophic level 2
trophic level 1
death + waste
death
weathering input
Human input
Output
Soil erosion
leaching removal
decomposers

Fig. 9.2 : Generalized pattern of nutrient cycling (after C.C. Park, 1980).

When nutrients are used and assimilated in the building of plant tissues and their bodies and when these are circulated and assimilated among different organisms of different trophic levels, these materials become **organic matter** and are stored in **biotic reservoirs or pools of organic phase.** The organic elements of plants and animals are released in a variety of ways as given below :

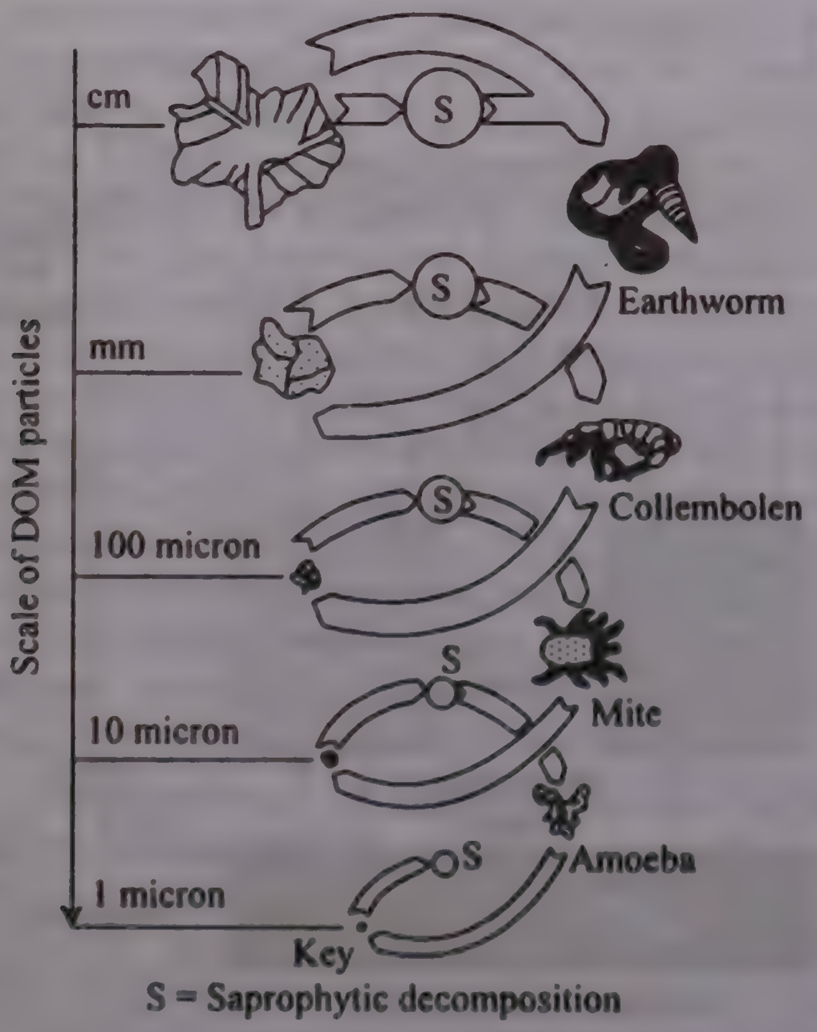

Scale of DOM particles
cm
mm
100 micron
10 micron
1 micron
S
Earthworm
Collembolen
Mite
Amoeba
Key
S = Saprophytic decomposition

Fig. 9.3 : The gradual degradation of dead organic matter (DOM) in the litter layer by saprophytes (after I.G. Simmons 1982).

(1) Through the **decomposition** of leaf falls from plants, dead plants, parts of plants and dead animals by microbes (decomposers) mainly bacteria (fig. 9.3). The gradual degradation of **dead organic matter** (DOM) in the litter layer by saprophytes (those organisms which feed on organic compounds of dead plants and animals) has been shown through fig 9.3. These organic materials after decomposition are again converted into inorganic materials which again join the soil pool.

(2) Through **burning of vegetation** by lightning, accidental forest fires or deliberate forest fires kindled by man. The portions of organic matter on burning are released to the atmosphere and again fall down on the ground surface under the impact of precipitation and again become soluble inorganic form of element to join **soil pool (soil storage)** while some portions in the form of ashes after their fall on the ground surfaces are decomposed by bacterial activity and these again join soil storage.

(3) The waste materials excreted or released by animals (dung, stool etc.) are decomposed by microbes (decomposers) (mainly bacteria) and are again converted into inorganic elements which again find their way in soluble form to **soil storage** (fig. 9.4).

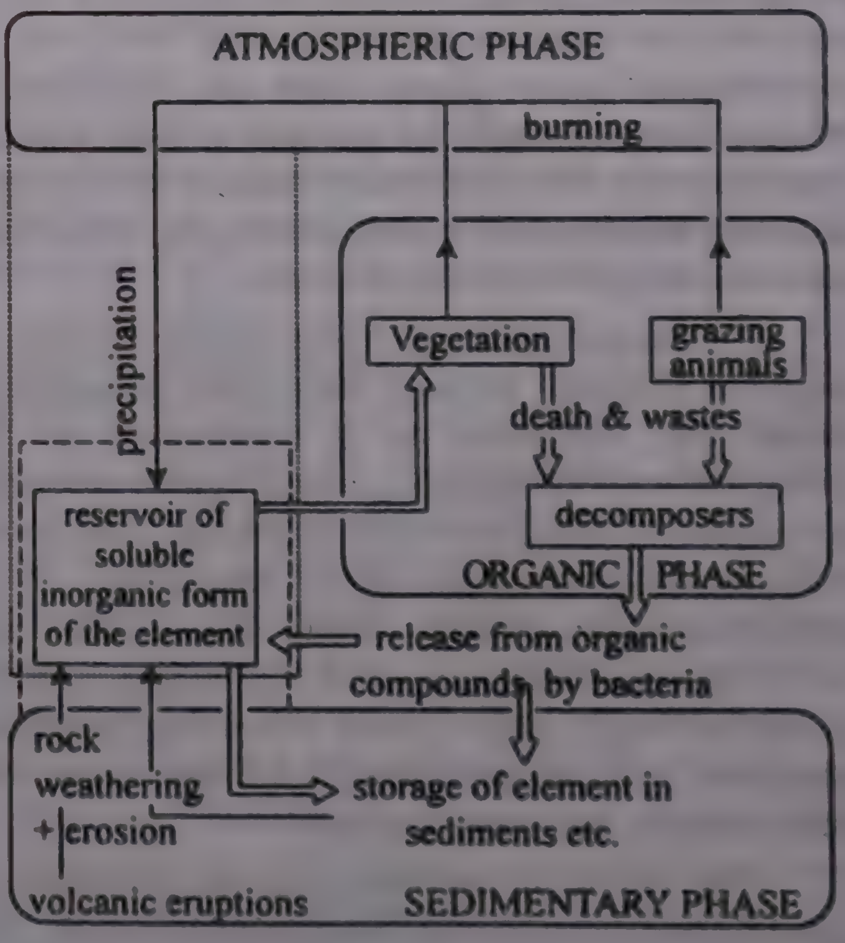

ATMOSPHERIC PHASE
burning
precipitation
Vegetation
grazing animals
death & wastes
decomposers
ORGANIC PHASE
reservoir of soluble inorganic form of the element
release from organic compounds by bacteria
rock weathering
+ erosion
storage of element in sediments etc.
volcanic eruptions
SEDIMENTARY PHASE

Fig. 9.4 : Pattern of terrestrial biogeochemical cycle. Solid arrows indicate major pathways of nutrients (after W.B. Clapham, 1973).

Thus it is obvious that biogeochemical cycles involve the movement and circulation of soluble inorganic substances (nutrients) derived from **sedimentary** and **atmospheric phases** of inorganic substances (sedimentary and atmospheric phases are two important basic components of inorganic phase of elements) through **organic phase** of various biotic componetns and finally their return to inorganic state. The study of biogeochemical cycles may be approached on two scales e.g. (i) cycling of all the elements together or (ii) cycling of individual elements e.g. water or hydrogen cycle, carbon cycle, oxygen cycle, nitrogen cycle, phosphorous cycle, sulphur cycle etc. Besides, hydrological cycle, sediment cycle, and mineral cycle are also included in the broader biogeochemical cycles.

9.2.1 HYDROLOGICAL CYCLE

About one third of the important 100 elements which occur naturally in the earth's crust are very important for the sustenance of life in the biosphere. Out of these essential elements oxygen, carbon and hydrogen are by far the most essential elements for the existence of living organisms because these three elements constitute 90 per cent of dry weight of the organic matter in the biosphere. Out of these three essential elements, hydrogen in the form of water and oxygen together make up 80.5 per cent of the total weight of all the living organisms. Since hydrogen enters the biosphere and goes out of the biosphere in the form of moisture mainly in liquid form, the hydrogen cycle is discussed in terms of water cycle or hydrological cycle.

The water resulting from the association of hydrogen (2 atoms, H_2) and oxygen (one atom, O) (H_2O) is by far the most abundant substance in the biosphere. The water is found on the globe in various forms e.g. (i) **gaseous form** (vapour and moisture), (ii) **solid form** (ice), and (iii) **liquid form** (water). The water is found in various locations e.g. lakes, ponds, tanks, rivers, oceans, groundwater, soils, surfae and subsurface rocks, living organisms, as water vapour in the atmosphere, as snow and ice in the high latitude (polar areas) and high altitude (hills and mountains) areas. The water is very important substance in the biosphere because (i) it is able to dissolve almost all substances, (ii it has great ability to store heat, (iii) it takes part in the nourishment of organisms, (iv) it helps in the circulation of elements in the biosphere etc.

The water or hydrological cycle at global scale involves the mechanisms of (i) evaporation of water from the oceanic water through insolation, (ii) conversion of water into water vapour or moisture, (first and second processes are almost the same), (iii) transport of atmospheric moisture over the oceans and the continents by atmospheric circulation, (v) release of atmospheric moisture in the form of precipitation (either in liquid form as water, or in solid form as snow and ice and other minor forms as dew, fogs etc.) over the continents and oceans, and (vi) eventual transfer of water received at the earth's surface to the oceans viz various routes and hydrological processes, important being surface run off and rivers (fig. 9.5).

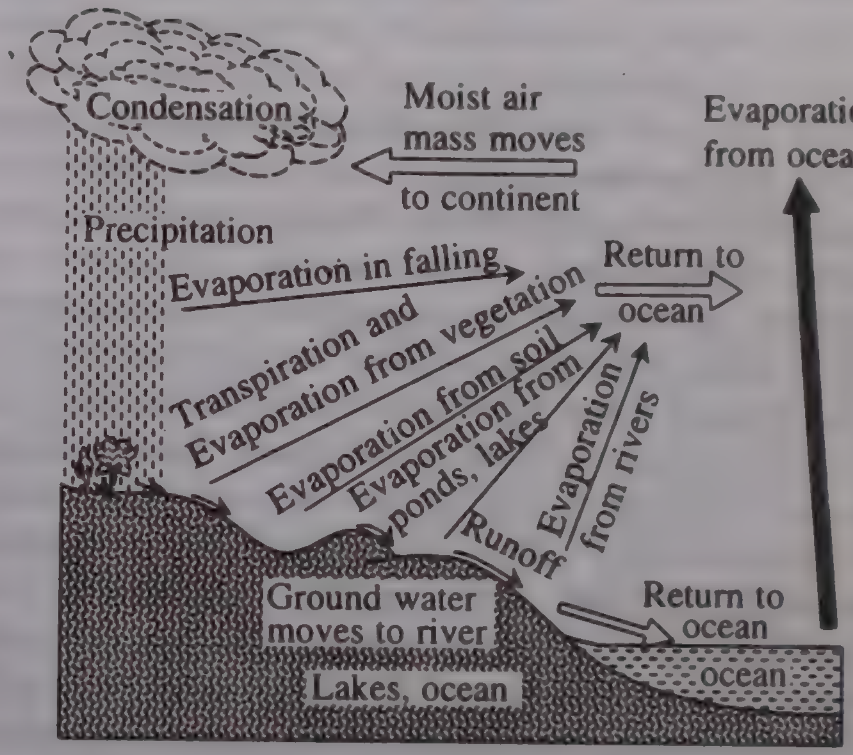


Fig. 9.5 : Global hydrological cycle involving different pathways of water e.g. from the ocean, through the atmosphere and the lithosphere back to the ocean.

The mechanisms of global hydrological cycle can be presented in the following manner :

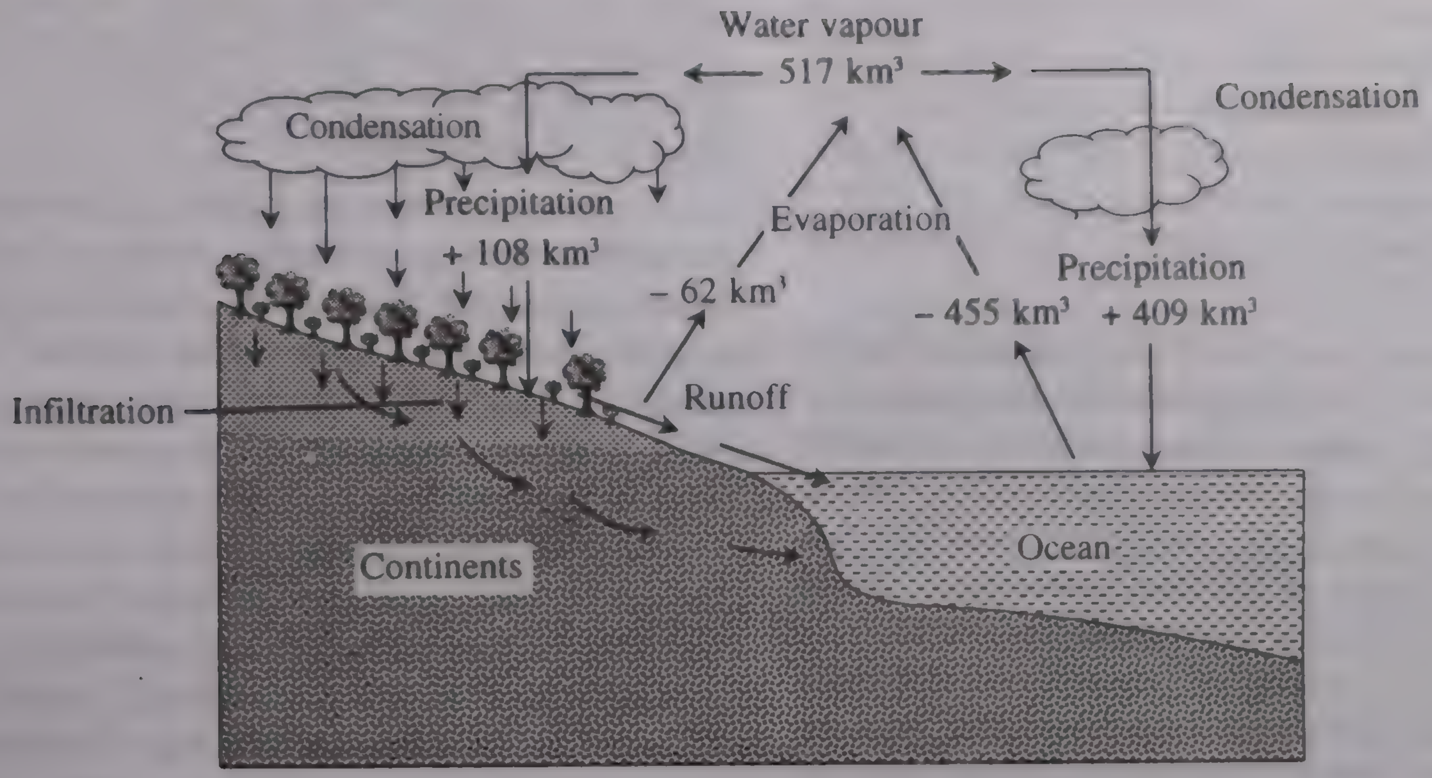
Oceanic water is heated by insolation and thus water is transformed (only a small fraction of oceanic water) into gaseous form-water vapour or moisture. This moisture is transported across the oceans and over the continents by atmospheric circulation (winds). The air is cooled because of its ascent and thus the moisture is released as precipitation over the oceans and the continents. The precipitation falls on the land in a variety of ways e.g. (i) Some precipitation falls directly in the streams, lakes and other bodies. This precipitation fall is called **direct fall** which is directly disposed off back to the oceans. (ii) Some portion of rainfall is intercepted by vegetation. Some portion of this intercepted rainfall is evaporated from the leaves and the remainder reaches the ground through the branches and stems of plants as **stem flow** or **aerial streams.** (iii) Some portion of rainfall reaches the ground directly as **throughfall.** Some portion of rainfall is lost to the atmosphere through evapotranspiration from the vegetation. Some water is also lost to the atmosphere through evaporation from the lakes, ponds, tanks and rivers.

A sizeable portion of rainfall reaching the ground surface becomes effective overlandflow which reaches the streams as surface runoff. Some portion of rainwater received at the ground surface enters the soil zone through infiltration and thus forms **soil moisture storage** of which some portion is again lost to the atmopshere through evaportion and plant transpiration, some portion reappears as seepage and springs via **throughflow** and **interflow** while some portion percolates further downward to form **ground water storage** of which soome portion reaches the channel through **base flow**, some portion moves upward as capillary rise to reach 'soil moisture storage' and some portion is routed further donward through **deep trnasfer** and enters the underlying bedrocks. The **channel storage** receives water from **surface storage** through runoff, from soil moisture storage through interflow and throughflow and from groundwater storage through base flow. Thus the initial input of precipitation finds exit through two paths of output e.g. (i) to the atmosphere through evaporation from rivers, lakes, ponds, soil, evapotranspiration from vegetation and evaporation of falling rains, and (ii) to the oceans through channel runoff or stream flow. This process is repeated every year to make the water or hydrological cycle at global scale effective.

It may be pointed out that though the different hydrological processes as elaborated above maintain the global hydrological cycle through the oceans, the atmosphere and the continents but out of the total moisture of the biosphere 95 percent is never available to hydrological cycle because it is (estimated quantity being 2,50,000 × 10^{20} grams) locked in the rocks of the earth's crust. Thus only 5 percent of the total moisture of the biosphere is available to the global hydrological cycle. Of this 5 percent of moisture about 97.2 percent is stored in the oceans and the remainder 2.8 percent is represented by 2.15 percent moisture stored in polar ice caps and permanent glaciers, 0.62 percent moisture in the form of groundwater (which is in circulation) and 0.03 percent moisture in the streams, soils, freshwater lakes, saline lakes and inland seas.

It is believed that the global hydrological cycle involves the balance between evaporation and precipitation over the earth's surface but the pattern of balance between evaporation and precipitation is not uniform over the oceans and the land. According to the estimate of M.L. Budyko (1971) evaporation exceeds precipitation over the oceans because 4,55,000 cubic km of water is evaporated from the oceans every year whereas only 409,000 cubic km of water is returned to the oceans through precipitation per annum. Thus there is net loss of 46,000 cubic km of water from the oceans every year. On the other hand 62,000 cubic km of water is evaporated from different water bodies of the land annually but 108,000 cubic km of water is annually received at the land through precipitation. Thus there is a net gain of 46,000 cubic km of water on the land every year. This is because of the fact that 46,000 cubic km of evaporated water from the oceans is added to atmospheric budget of moisture over the land. The additional amount of 46,000 cubic km of water is disposed off to the oceans through stream runoff every year (fig. 9.6).

Hydrological cycle is very important mechanism for various biological processes in the biosphere because no life is possible without water. Though the interaction between vegetation and hydrological cycle is very limited but the effect of hydrological cycle on the biosphere (viz. vegetation) is enormous because the vegetation is an effective medimum for the circulation of sediments and chemical elements through biogeochemical cycles in the biosphere and all these cycles become possible only through the movement of water. Though human activities have not adversely affected the hydrological cycle at present to a significant level but man through his everincreasing economic activities may affect various components of hydrological cycle in a variety of ways as elaborated below :



Numbers in 000.

Fig. 9.6 : Global hydrological balance. Source : data from M.L. Budyko (1971).

Man affects and modifies the internal processes of hydrological regime of drainage basins in a variety of ways. These modifications have both positive and negative effects. The input of precipitation in the hydrological cycle of a drainage basin is modified through **'cloud seeding'** (also see page 293) for induced precipitation (increase in input), atmospheric pollution (both increase and decrease in precipitation input), modified atmospheric circulation (e.g. urbanisation induces vertical convective currents and thus increases precipitation), forest clearance (decrease in precipitation), vegetation modification (changes in precipitation) etc. Additional input of water on ground surface is provided through irrigation of crops and effluent disposal from urban areas. **Interception storage** is modified by forest clearance (reductionn in interception storage) and vegetation modification. **Surface storage** is modified by land clearance, cultivation, urbanisation, land drainage, mining etc. while **surface runoff** is increased due to deforestation and cultivation and is supplemented by additional input through channeled irrigation for cropland and effluent disposal from urban areas. **Infilration** is modified through devegetation (decrease in infiltration), urbanisation (decrease), afforestation and reforestation (increase) and irrigation (increase). **Soil moisture storage** is positively affected by irrigation, planting of grasses and plants, artificial recharge, seepage from water supply systems, soakpits, cesspools etc. while it is negatively affected by land clearance through deforestation, burning of grasslands, urbanisation etc. **Groundwater storage** is modified through extraction of groundwater for domestic use and irrigation purposes while **channel storage** is modified through flood plain development, channel modification (shortening or lengthening of channels), river regulation, construction of dams and reservoirs etc. The impact of man's activities on different components of basin hydrological cycle may 'include increased flood hazard and other changes in river regime, reduced availability of groundwater, deterioration of water quality and widespread eutrophication of water bodies and river systems in response to increased nutrients' (K.J. Gregory and D.E. Walling, 1981)

9.2.2 CARBON CYCLE

The carbon which moves in the biosphere through various parthways has three phases of its storage and movement e.g. (i) gaseous phase in which carbon is present as gas (CO_2) in the atmosphere, (ii) liquid phase which includes dissolved carbon dioxide in water, and (iii) solid phase which includes carbon stored in the sediments, fossil fuels and organic matter. 'The movement of carbon in solid and liquid forms and as carbon dioxide (gaseous form) is of particular interest as it makes up around 50 percent of organic matter by dry weight, and its movemetns within the biosphere are closely bound up with the flow of energy' (P.A. Furley and W.W. Newey, 1982).

The carbon cycle involving the circulation of carbon within the biosphere includes two pathways or cycles e.g. (i) **gaseous cycle,** which involves the movement of carbon as carbon dioxide (CO_2) which is found as free gas in the atmosphere and as a gas dissolved in the water of the land and of the seas and the oceans, and (ii) **non-gaseous or inorganic cycle** involves the solid phase of carbon wherein it resides in carbohydrate molecules (CH_20) in the organic matter, as hydrocarbon compounds in the rocks of the earth's crust (in coal etc.) and as mineral carbonate compounds such as calcium carbonate.

The carbon dioxide of the atmospheric pool enters the biological cycles through the process of photosynthesis wherein carbon, hydrogen and oxygen are combined by the autotrophic green plants of the terrestrial and marine ecosystems with the help of sunlight and thus organic compounds are formed. The flow of energy and elements in the ecosystem (biosphere) is controlled by different components of the system. The component whcih issues energy or element is called **donor component** and the compoent which receives energy or elements is called **recipient component.** In the case of carbon cycle in the biosphere the transfer of carbon from the atmospheric pool or reservoir (donor component) to the living organisms or organic reservoir (recipient component) is both **donor-controlled** and **recipient controlled.** The rate of uptake of carbon dioxide by green plants (recipients) from the atmospheric reservoir depends on the density of plants and their activities (receipient controlled) and on the concentration of carbon dioxide in the atmosphere and other environmental factors (light, water, nutrients etc. and processes (donor controlled).

Thus the carbon dioxide assimilated by plants is stored in the woody tissues of plants. This is called as **organic reservoir** (fig. 9.7) of carbon. Forests, mainly tropical evergreen rainforests, temperate evergreen and deciduous forests, and the boreal forests are significant storages (reservoirs) of biological carbon of the biosphere. Carbon is released from the living organisms due to breakdown of carbohydrates during respiration. The respiration by the biota transforms organic compounds to gaseous carbon dioxide which is returned back to the atmospehre.

Some of the carbohydrates (chemical energy) produced by the autotrophic plants at trophic level I are consumed by the herbivourous animals at trophic level 2 and carnivorous animals at trophic levels 3 and 4 and these heterotrophic animals release carbon as carbon dioxide due to breakdown of their carbohydrates (during respiration, fig. 9.7). Decomposition of fallen leaf litter, and dead organic tissues (of both plants and animals) by decomposers oxidizes further carbon to carbon dioxide which is returned back to the atmosphere. Some carbon is released as CO_2 due to burning of vegetation and animals and is returned back to the atmospheric reservoir. The microbes or decomposers also release carbon in gaseous form through respiration when they decompose dead organic tissues.

Some carbon goes to the sediments below the ground surface and is stored in **sedimentary reservoir.** Some of the dead organic matter is also stored in the soil or in deep-sea sediments for longer period of geological time. The terrestrial organic matter is transported to the oceans by the geological processes in the form of dissolved or particulate organic matter. The geological processes include rivers, wind, glaciers etc. The organic materials brought to the oceans are generally converted into rocks and thus carbon enters the sedimentary phase.

The sedimentary reservoir or geological reservoir stores carbon mainly in the form of inorganic carbonates and to some extent in the form of peat, soil or coal or animal (e.g. shells, bones etc.) remains, or mineral oil. Carbon has a long residence time in the sedimentary phase because it remains stored in the sedimentary reservoirs for fairly a longer period of geological time. Carbon from the sedimentary phase may be released only when either (i) the rocks are weathered and eroded, or (ii) the fossil fuels (coal, peat, petroleum and natural gas) are burnt during their uses in the factories, automobiles or domestic affairs. Carbon released from the sedimentary reservoirs (through weathering and erosion of rocks, burning of fossil fuels and volcanic eruption) goes back to the atmospheric reservoir but this sedimentary cycle of carbon takes much longer time of geological time scale.

The movement of carbon in the marine ecosystem is much simpler. Atmospheric carbon dioxide is taken by the marine autotrophic phytoplanktons who transform carbon together with oxygen and hydrogen into carbohydrates during the process of photosynthesis. Some portion of carbon stored in phytoplanktons goes to sedimentary storages after their death, some portion is transformed into organic matter to form petroleum and natural gas and some portion is transferred to marine animals when they feed on phytoplanktons and on such animals which feed on zooplanktons. Some portion of carbohydrates stored in the marine animals is broken down during respiration and thus carbon is released from marine animals as carbondioxide which is returned back to the atmospheric reservoir. The remaining portion of carbon of marine organisms goes to sedimentary reservoir as carbonate sediments and hydrocarbons. Carbon stored in the sedimentary reservoirs may be released to the atmosphere after long period of geological time scale through weathering and volcanic eruption (fig. 9.7).

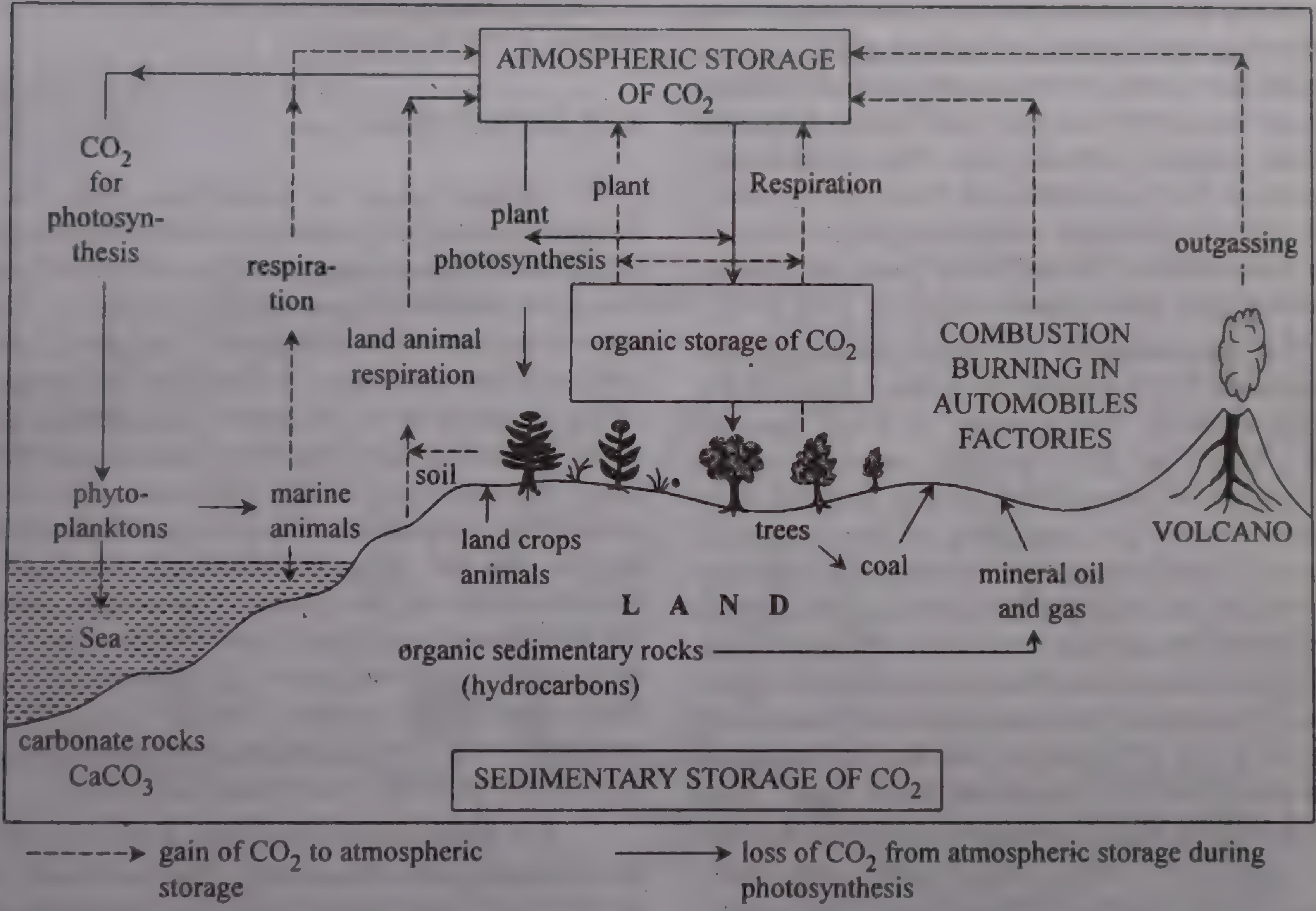

ATMOSPHERIC STORAGE OF CO_2
CO_2 for photosynthesis
respiration
plant
plant
photosynthesis
Respiration
outgassing
land animal respiration
organic storage of CO_2
COMBUSTION BURNING IN AUTOMOBILES FACTORIES
soil
phyto-planktons
marine animals
land crops animals
trees
coal
mineral oil and gas
VOLCANO
Sea
L A N D
organic sedimentary rocks (hydrocarbons)
carbonate rocks $CaCO_3$
SEDIMENTARY STORAGE OF CO_2
------> gain of CO_2 to atmospheric storage
——> loss of CO_2 from atmospheric storage during photosynthesis

Fig. 9.7 : Illustration of simplified carbon cycle.

Summary of Carbon Cycle

The aforesaid mechanism of gaseous and non-gaseous carbon cycles may bs summarized in the following manner :

Carbon is spent from the atmospheric reservoir (pool or storage) of carbon dioxide in the formation of carbohydrates by the autotrophic terrestrial plants and marine phytoplanktons and thus carbon is stored in the organisms of different trophic levels of terrestrial and marine ecosystems **(organic pool/storage of carbon)**. The atmospheric pool receives carbon from the respiration of microbes or decomposers (soil respiration), animals and plants of terrestrial ecosystems and from the respiration of phytoplanktons and animals of marine ecosystem, from the combustion of fossil fuels(coal and petroleum) (that is carbon from man's industrial role), from automobiles and aeroplanes and from volcanic eruption.

The **sedimentry storage pool** receives carbon from skeletal structures of calcium carbonate built up by phytoplanktons. These structures are disintegrated and decomposed into inorganic mineral matter which accumulates on the ocean floor and is converted into sedimentary strata. Carbon is stored in these sedimentary state of carbonate rocks for long period of geological time and is not readily available to general carbon cycle. Organic compounds synthesized by marine phytoplanktons settle down on the ocean floor and are transformed into hydrocarbons (pertoleum and natural gas) and thus these join the sedimentary storage pool of carbon. Plants are converted into peat and coal on the lands and thus organic carbon joins the sedimentary storage pool. Carbon is released from the sedimentary storage pool through weathering and erosion of rocks, combustion of fossil fuels (coal, petroleum and natural gas) and volcanic eruption (Fig. 9.7).

The concentration of carbon dioxide in the atmosphere is 0.036 percent of the total gases of the atmosphere which is equivalent to 0.007 percent carbon. There has been gradual increase in the concentration of atmospheric carbon dioxide. It is estimated that at the beginning of the industrial revolution (1860) atmospheric carbon dioxide was 290 ppm (part per million) and since then the carbon content in the atmosphere has risen to 360 ppm (upto 1990). It is estimated that there is addition of carbon content to the atmospheric storage pool of carbon at the rate of 5-6 $\times 10^9$ tons per year due to release of carbon from the combustion of fossil fuels. This means that there is an increase of carbon at the rate of 2-3 ppm per year. D.R. Kester and R.M. Pytkowicz (1977) have predicted that if the present rate of increase of CO_2 is maintained there will be fourfold increase in the atmospheric carbon within about 80 years. According to another estimate the concentration of carbon in the atmosphere was predicted to reach 300 to 400 ppm by the turn of the 20th century which has come almost true. It has been predicted by IPCC (Intergovernmental Panel on Climate Change) Report of 2001 that the CO_2 concentration may go upto 540-970 ppm which may cause rise in global termperatue by 1.4^0-5.8^0C by the trun of 21st century. The gradual increase in the concentration of CO_2 in the atmosphere would have far reaching consequences on all living organisms including man. Increase in carbon dioxide leads to chain effects in the biosphere, as CO_2 increase→temperature of both the land and water surfaces increases→which may affect evaporation, precipitation, melting of ice caps and ice sheets. All these affect broader world climatic patterns. There will be considerable rise in the sea level consequent upon the melting of glaciers, ice caps and ice sheets due to increase in temperature. Increase in carbon dioxide will also lead to increase in the **greenhouse effects** of the atmosphere which means increase in temperature. This trend will adversely affect the living organisms in the biosphere (see section 13.9, chapter 13 of this book).

9.2.3 OXYGEN CYCLE

Oxygen plays a significant role in the biosphere and is very essential element for the living organisms because it supports life and arises from it. The circulation of oxygen also helps in the cycling of other elements in the biosphere. Oxygen is chemically very active because it combines with majority of the elements in the biosphere. It generally forms about 70 percent atoms in living matter and plays a very important role in the formation of carbohydrates, fats and proteins. It is required for respiration process by the animals including man and for photosynthesis by the plants. The oxygen cycle in the biosphere is very much complicated because of its various chemical forms e.g. molecular oxygen (O_2), water (H_2O), carbon dioxide (CO_2), different inorganic compounds as oxides (iron oxides-Fe_2O_3), carbonates (calcium carbonate-$CaCO_3$) etc.

It is believed that there was no free oxygen in the original earth-atmosphere. The molecular oxygen probably was formed only after the development of photosynthesising organisms due to splitting of water molecules by plant cells. Water is split by plant cells and is reconstituted in about every 2 million years and thus oxygen produced circulates in the atmosphere through various components and is again recycled after about 2000 years. Thus it is obvious that the residence time of oxygen in the atmosphere is much longer (2000 years, that is oxygen is recycled in 2000 years) than the residence time of carbon (300 years, that is the carbon released by plants and animals through respiration is available again for them after 300 years). The oxygen continued to concentrate in the atmosphere from the time of its formation and now it constitutes about 21 percent of the total gaseous composition of the atmosphere. It is important to note that oxygen remains in molecular oxygen form (O_2) for very short time because it readily combines with CO_2 or H_2O or with other oxide forms.

Oxygen is produced through the process of photosynthesis by the autotrophic green plants of terrestrial ecosystems and phytoplantktons of marine ecosystems and to a lesser extent by the reduction of various mineral oxides. Oxygen, thus produced, enters the **atmospheric storage pool.** Every year some oxygen is also added to the atmosphere from volcanic eruption through outgassing mainly in the form of CO_2 and H_2O. Oxygen from the atmospheric storage pool is used by marine and terrestrial animals during respiration. Oxygen is also consumed during burning of wood and fossil fuels. Some portion of oxygen in the form of oxides is incorporated in the drainage waters and ultimately reaches the oceans and is incorporated in the sediments. Thus oxygen enters the **sedimentary storage pool** and remains there for considerably a longer period of geological time scale. Thus the oxygen cycle involves the input of oxygen to the atmospheric storage pool from the photosynthesis of marine and terrestrial autotrophic plants and from volcanic eruption and the loss of oxygen from the atmospheric storage pool through respiration of marine and terrestrial organisms and minerals oxidation, burning of wood, grasses and forest fires, combustion of fossil fuels (coal and petroleum) etc. (fig. 9.8).

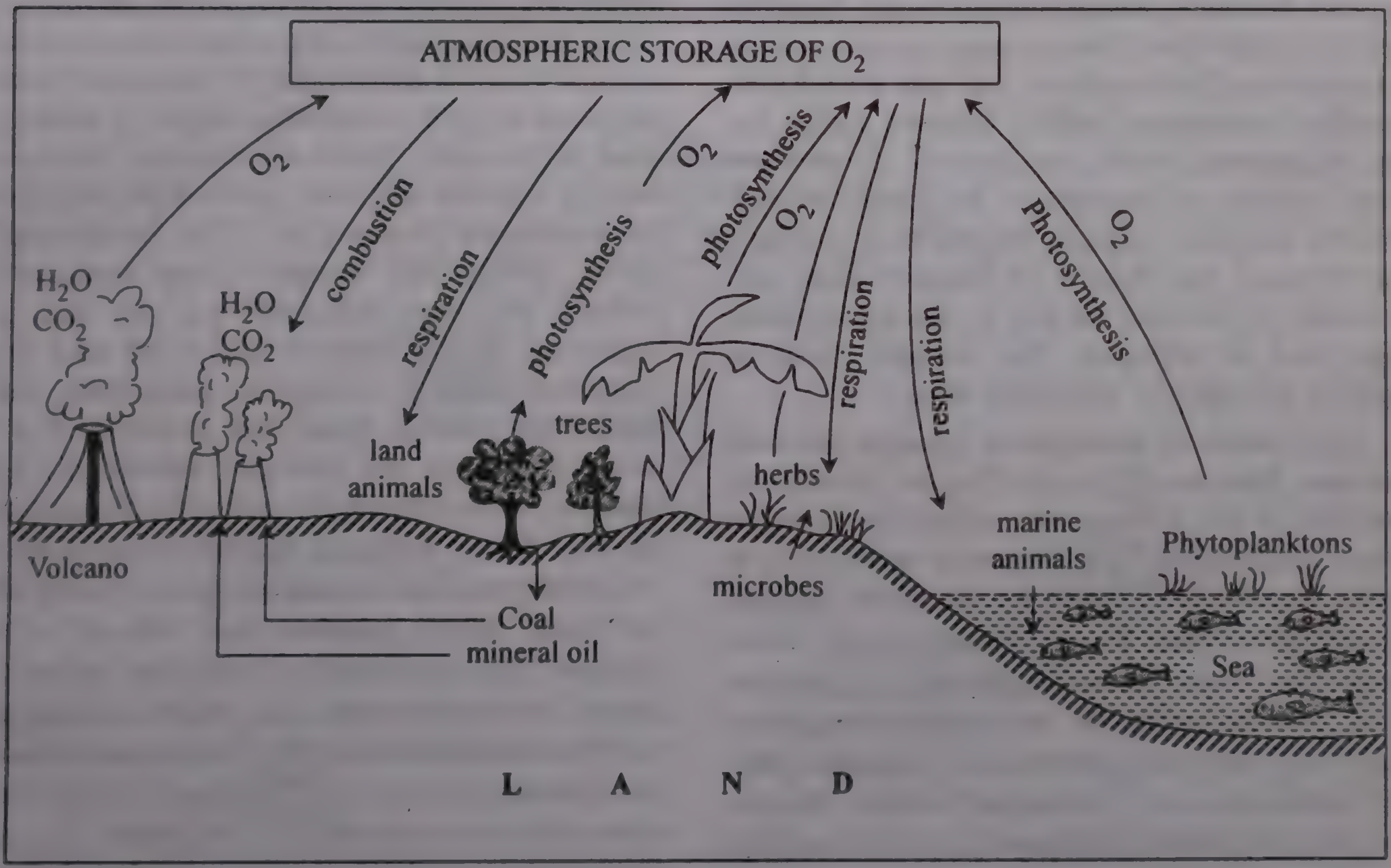

ATMOSPHERIC STORAGE OF O2
O2
combustion
respiration
photosynthesis
O2
photosynthesis
O2
respiration
respiration
Photosynthesis
O2
H2O
CO2
H2O
CO2
land animals
trees
herbs
Volcano
microbes
Coal
mineral oil
marine animals
Phytoplanktons
Sea
L A N D

Fig. 9.8 : Illustration of simplified oxygen cycle.

The consumption of oxygen has increased after the Industrial Revolution in 1860. It is estimated that very high rate of industrial combustion in the industrialized world, mainly the U.S.A. and the Western Europe, uses more oxygen annually. Since the proportion of vegetation cover is decreasing and the industrial expansion is increasing, the imbalance betweeen the amount of consumed and regenerated oxygen may be serious concern to human society.

9.2.4. NITROGEN CYCLE

'Nitrogen moves through the biosphere in a gaseous cycle in which the atmosphere, containing 78 percent nitrogen by volume, is a vast storage pool available to organisms' (A.N. Strahler and A.H. Strahler, 1976). Nitrogen is very important for all life forms in the biosphere because it is an essential part of amino acids which make up proteins. Nitrogen generally exists in seven forms in the atmosphere e.g. molecular nitrogen (N_2), oxides of nitrogen (e.g. N_2O = nitrous oxide, NO = nitric oxide and NO_2 = nitrogen peroxide) and hydrogen-nitrogen compounds (e.g. NH = amino, NH_3 = ammonia and HNO_2 = nitrous acids). Though nitrogen constitutes the largest proportion of atmospheric gases by volume, but living organisms cannot use nitrogen directly rather they obtain nitrogen in the form of ammonium salts and nitrate through their roots from the soils. Animals get nitrogen from the plants by eating them. The nitrogen cycle involves the conversion of atmospheric nitrogen into different usable compounds (which become usable for living organisms) under the process of **nitrogen fixation;** transfer of nitrogen to the plants through their roots from the soils and liberation of nitrogen as gas through the process of denitrification and final return of nitrogen as gas to the atmospheric storage pool of nitrogen. The nitrogen cycle is completed through the following steps :

(1) Transfer of atmospheric nitrogen into soils or nitrogen fixation—Nitrogen fixation means the conversion of the atmospheric molecular nitrogen (N_2) into usable forms (e.g. ammonia and nitrate) in the soils which can be taken by the plants through their roots-the process known as **root osmosis.** There are only two major natural pathways of nitrogen fixation or conversion of molecular atmospheric nitrogen into ammonia, nitrate ion or amino acids e.g. (i) **lightning,** and (ii) **biological activity.** There is also **artificial fixation of nitrogen** by man through the use of chemial fertilizers.

(i) Molecular atmospheric nitrogen and oxygen are combined by natural lightning discharge to form nitiric oxide (NO). Due to additional oxygen nitric oxide is oxidized to form nitrogen peroxide (NO_2) which changes to nitric acid (HNO_3) after combining with water (H_2O). This acid (nitric acid) is brought to the soils by rainwater where it changes to nitrates after reacting with calcium carbonates ($CaCO_3$) and alkalis. These nitrates accumulate in the soils and are used by plants as nutrients to prepare their food. The aforesaid processes of fixation of nitrogen by atmospheric processes may be expressed in the following forms :

Lightning Discharge

↓

$N_2 + O_2 \rightarrow 2NO$ (nitrogen oxide)

$2NO + O_2 \rightarrow 2NO_2$ (nitrogen peroxide)

$4NO_2 + 2H_2O + O \rightarrow 4HNO_3$ (nitric acid)

$4HNO_3 + CaCO_3 \rightarrow Ca(NO_3)_2 + CO_2$ (calcium nitrate)

It is estimated that this process of nitrogen fixation results in the formation of 2,50,000 tons of acid within 24 hours.

(ii) The other natural process of nitrogen fixation is performed by the activities of the organisms. 'One of the more curious and important points we should keep in our mind about the nitrogen cycle is that the conversion of molecular nitrogen ammonia or nitrate, and other chemical transformations of inorganic forms of nitrogen, can be done only by bacteria and blue-green algae-members of the prokaryotic forms of life' (D.B. Botkin and E.A. Keller, 1982). The nitrogen fixing organisms are divided into two categories e.g. (i) free living organisms mainly bacteria and algae, and (ii) the organisms having symbiotic association include plants and bacteria which live together. The free-living organisms are basically autotrophic organisms like bluegreen alagae and some photosynthetic bacteria. Many symbiotic bacteria living in the roots of leguminous plants (like peas, gram, clover, alfafa, soybeans, beans, peanuts etc.) help in nitrogen fixation. It is important to note that bacteria and plants live in close physical contact where plants provide nutrients and organic compounds to bacteria and bacteria in turn supply nitrogen in the form of ammonium or amino acids to the plants. The micro-organisms e.g. bacteria continuously transfer atmospheric nitrogen in the soils and make nitrogen usable for plants. Nitrogen fixation is done in the oceans by non-symbiotic organisms which include bacteria and blue-green algae.

(iii) The artifical method of nitrogen fixation includes the production of chemical fertilizers (e.g. ammonium suplhate, calcium sinemide, nitrates etc.) by man in the factories.

(2) Mineralization, nitrification and transfer of nitrogen from soils to plants and animals : Mineralization and nitrification are the processes of transformation of nitrogen in such forms in the soils that these can be easily taken up by plants. When organic nitrogenous compounds are transformed into an inorganic or mineral form (either ammonia or ammonium), the process is called mineralization or **ammonification** where as the process of the conversion of ammonium salts into nitrite and nitrate is called **nitrification.** Thus plants take nitrogen in the form of nitrates from the soils through their roots. Nitrogen taken up by plants (in the form of nitrates) is transformed into complex organic compounds (e.g. protein) which are transferred to herbivorous animals of trophic level 2 where plant protein (having nitrogen) is converted into animal protein. Again nitrogen (in the form of animal protein) is transferred to carnivorous animals at trophic levels 3 and 4. The protein disintegrates in the bodies of organisms and is transformed into amino acid, urea etc.

(3) Denitrification and return of nitrogen to the atmosphere : Ammonifying bacteria living in the soils convert amino acid and urea present in the excreted wastes of the animals into ammonia and ammonium salts. Similarly, soil-living bacteria decompose dead plants or their parts and dead animals and transform amino acid and urea present in them into ammonia and ammonium salt. These ammonium salts and ammonia are again transformed into nitrates by nitrifying or nitrosifying bacteria, the process being known as **nitrification** as referred to above.

The opposite process of nitrification is known as **dinitrification** which means transformation of nitrates into gaseous nitrogen (molecular nitrogen) by denitrifying bacteria and fungi which operate in anaerobic conditions which goes back to the atmospheric storage pool and thus the nitrogen cycle

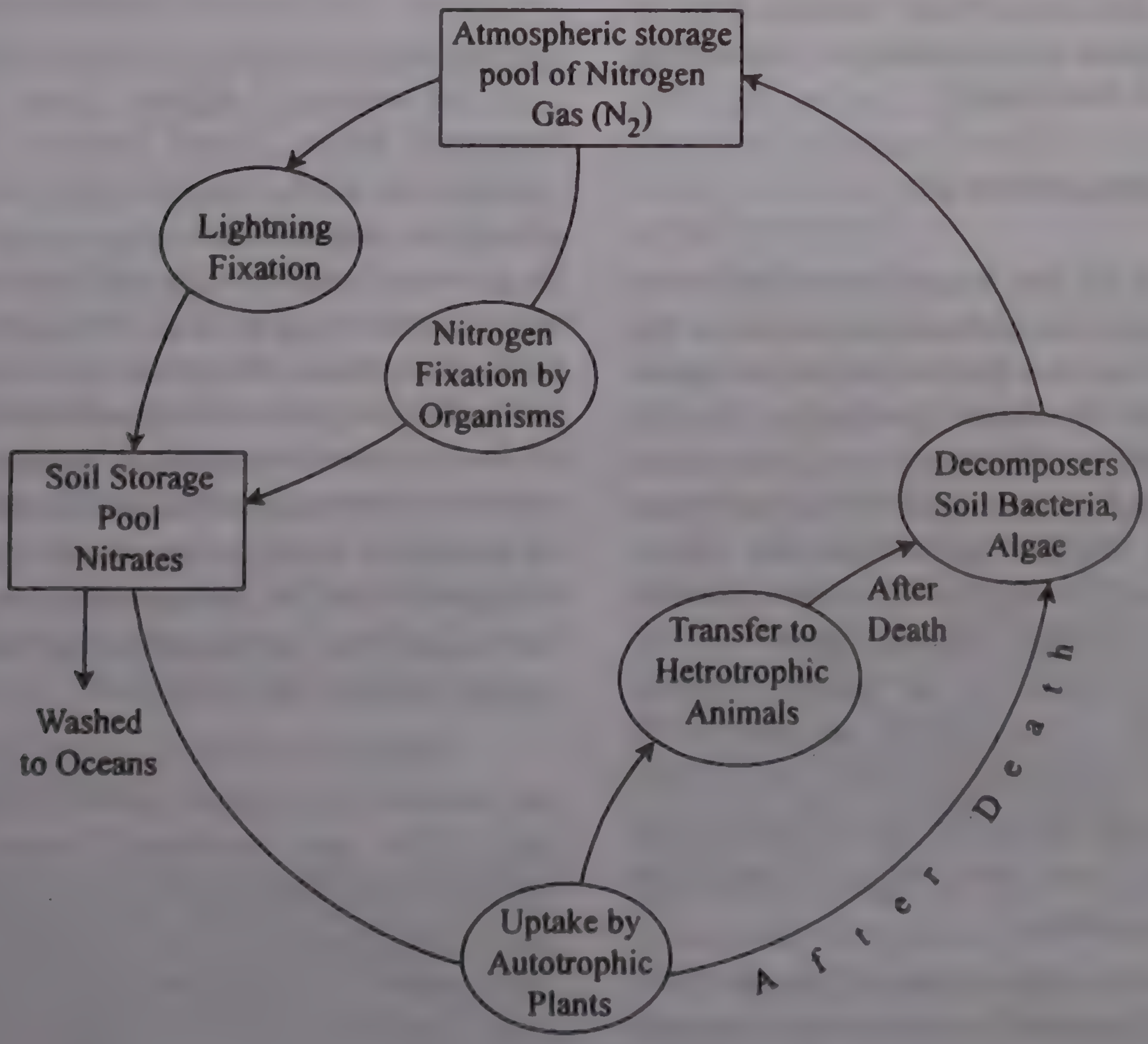

Atmospheric storage pool of Nitrogen Gas (N_2)
Lightning Fixation
Nitrogen Fixation by Organisms
Soil Storage Pool Nitrates
Washed to Oceans
Decomposers Soil Bacteria, Algae
After Death
Transfer to Hetrotrophic Animals
Uptake by Autotrophic Plants
After Death

Fig 9.9 : Nitrogen cycle.

is completed (fig. 9.9). Some of the nitrates are also lost to groundwater and some are lost to the sea through erosion and transport by stream runoff. Bacterial decomposition of organisms releases ammonia to the atmosphere, which being soluble in water is returned back to the oceans and continents with rainfall in the form of ammonium sulphate and ammonium nitrate. It is important to note that organisms are the controling and regulating factors of the nitrogen cycle because bacteria fix nitrogen and perform the process of nitrification as well as these also perform denitrification. It is evident that the 'removal and addition of nitrogen to the atmosphere are primarily controlled by bacterial activity' (D.B. Botkin and E.A. Keller, 1982).

It is expected that the removal of nitrogen from the atmospheric storage pool and fixation of nitrogen by terrestrial and marine organisms should be balanced by the addition of nitrogen through denitrification from the terrestrial and marine ecosystems but the amount of nitrogen available to plants is much larger than the amount of nitrogen returned back to the atmopsheric storage pool by denitrification because of increased use of industrial nitrogen (chemical fertilizers).

9.2.5 PHOSPHOROUS CYCLE

Phosphorous is the second most important (water being the most important) substance in the biosphere which is most essential for the growth of organisms because it limits production in the biospheric ecosystem. Phosphorous is in short supply as it is found in phosphate rocks which are restricted to very limited areas over the globe. Phosphorous is such a chemical element (mineral) which has a very limited gaseous phase and has major sedimentary phase in the biogeochemical cycle. Phosphorous is temporarily present in the atmosphere in very small quantity in the form of dust and salt which are carried as salt spray from the sea or blown as dust from the areas of phosphate deposits and active mines.

The very interesting feature of the phosphorous cycle is that it is gradual, very slow and one way as phosphorous tends to move from the lands to the oceans through surface runoff via rivers and very little amount of phosphorous is returned from the oceans to the lands. Most of phosphorous is stored in the sedimentary rocks in the form of phosphate rocks. When these rocks are weathered, phosphorous is transferred to the soil storage pool. It is significant to point out that phosphorous exists in the soil in the form of minerals combined with calcium, potassium, magnesium, iron and phosphate. Not all phosphorous present in the soils and rocks takes part in the cycle rather only 10 percent is involved in the cyclic pathways because phosphorous is relatively insoluble in water.

Plants take up phosphorous in the form of inorganic phosphate from the soils through their roots under the process of root osmosis. The inorganic phosphates are converted into organic forms in the plants which (organic forms of phosphate) are circulated in the food chain through different trophic levels (from plants to herbivorous animals and from herbivores to carnivorous and omnivorous animals). Phosphate is returned back to the soils when dead organisms (plants and animals) and their excreted wastes are decomposed by soil-organisms (decomposer organisms-microbes) and through mineralization of organic form of phosphate (i.e. conversion of organic form of phosphate to inorganic form). Some portion is leached and washed out to the oceans while some portions of phosphate are maintained as organic compounds (e.g. bones) which store and preserve phosphatic materials for long period. These are returned to the soils when these are again converted into mineral forms but this process is completed after long period of time. It is also important to state that a sizeable portion of phosphate absorbed by the plants remains in inorganic form in the plants and therefore this inorganic form of phosphate is mineralized after decomposition of plants in a relatively shorter period of time (fig. 9.11).

The return of phosphorous from the oceans to the lands is not regular feature rather it is exceedingly slow and occasional feature. Phosphorous brought to the littoral areas of the seas and the oceans is returned back to the lands through salt spray, fish (when eaten by terrestrial animals mainly man) and birds but major portion of phosphorous drained to the seas and the oceans is moved in the deeper sediments. In such cases, phosphorous may be available again only when there is emergence or upliftment of oceanic bottoms.

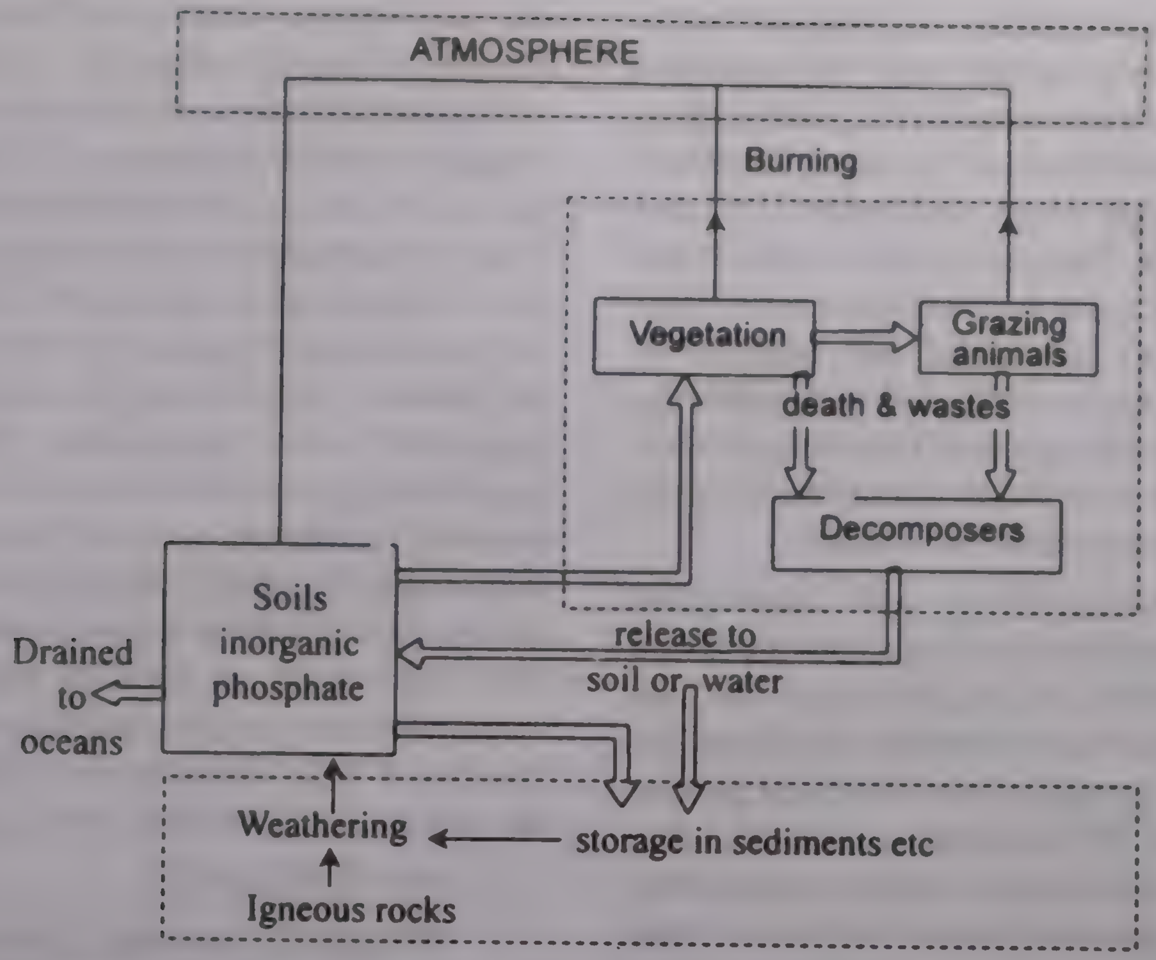


Fig. 9.10 : The phosphorous cycle (based on E.P. Odum, 1971).

It is estimated that an amount of 20,000,000,000 million meteric tonnes of phosphorous is stored in the rocks of the earth's crust but only 10,000 to 60,000 million meteric tonnes are minerable by conventional techniques, while ocean deposits account for 100,000,000 million metric tonnes of phosphorous. Since there is gradual removal of phosphorous from the lands to the oceans and there is very slow, almost negligible, return of phosphorous from the oceans to the lands, the amount of terrestrial phosphorous is gradualy decreasing whereas the demand of phosphorous by plants is increasing. Since phosphorous is the most critical element for the plants, additional phosphorous in the form of industrial fertilizers is added to the soils by man.

9.2.6 SEDIMENT CYCLE

The sediment cycle involves the creation of rocks, their disintegration and decomposition into sediments, the movement of sediments through the earth's environment and deposition of sediments and again the formation of rocks. The major processes involved directly and indirectly in the sedimentary cycle are endogenetic processes mainly tectonic forces and movements and exogenetic processes of running water (river), wind, glaciers and sea waves. The entire mechanism of the sediment cycle as referred to above is called **geocycle** which is the slowest of all the cycles which operate in the biosphere.

Water cycle, motored by the solar energy, is the main propellant of the sediment cycle though the major components of the sediment cycle e.g. weathering, erosion and deposition are also affected and controlled by wind and glaciers and biotic community which are also affected by the atmospheric processes. Endogenetic forces caused by thermal conditions of the mantle and the outer core and the superincumbent load create surface irregularities on the earth's surface through diastrophic movement e.g. creation of mountains, faults, plateaus, lakes etc. and secular rise in the continents and sea-floor and through sudden forces (e.g. earthquakes which cause faults, fractures, depressions etc. and vulcanicity which causes volcanic cones mountains, lava plains and plateaus).

The exogenetic or denudational processes are always busy to remove the vertical irregularities of the earth's surface caused by endogenetic forces. The uplifted landmasses are weathered (by physical or mechanical weathering,chemical weathering, biological weathering and physico-biochemical weathering) and continuously eroded and the resultant sediments are ultimately deposited in the geosynclines (a long, narrow and shallow tract of water bordered by landmasses) though some sediments are also deposited on the lands. The geosyclines when filled up with the sediments (in a very long period of time e.g. millions of years) are folded and uplifted as mountains which are again subjected to weathering and erosion resulting into gradual lowering of their height and continuous deposition of sediments in the geosynclines and the seas and the oceans.

Continuous sedimentation and consequent increase of superincumbent load on a lower portion of the geosyncline increases the pressure to such an extent that the geosynclinal sediments are altered by pressure, heating, deformation and fusion at greater depth which results in the formation of magma due to melting of sedimentary strata or pre-existing other rock strata. This mechanism causes valcanicity and seismic events. All these processes operate at a very large spatial scale involving longer period of geological time scale (millions of years) which may be of relevance to the long-term stability of the biospheric ecosystem. But a few components of the sediment cycle (e.g. weathering, erosion and deposition) are of immediate importance to the plants and animals in the biosphere and other forms of biogeochemical cycles (e.g. water cycle, chemical element/nutrient cycle etc.) which affect all types of organisms in the biosphere.

Weathering and erosion are very important components of the sediment cycle because these are the processes which help in the removal of chemical elements from the sedimentary phase and make them available to hydrological or water cycle which circulates these chemical elements in the various components of the biospheric ecosystem. Weathering and erosion thus affect the organisms in the biosphere though indirectly. Erosion is influenced by the precipitation component and the vegetation compoent of the biosphere. It is significant to point out that increased precipitation increases the erosion of the ground surface but it also increases vegetation cover which offers protective cover to the ground surface against erosion. It is obvious that erosion of the ground surface and the soils increases as the vegetation cover decreases. The soil erosion, a significant part of the sediment cycle, is of primary concern to human society in particular and other organisms in general because soil erosion adversely affects agriculture in a given area. Several attempts have been made to identify the factors which are responsible for accelerated rate of soil erosion. D. D. Smith and W.H. Wischmeier (1962) have presented the following Universal Soil Loss Equation :

$$A = R.K.L.S.C.P.$$

Where A = average annual sediment loss in kg/ha (kilogram per hectare); R = rainfall factor; K = soil erodibility factor; L.S. = slope length and steepness factor; C= cropping and soil management factor and P = measures of conservation practice.

Man has become very potent factor of weathering and erosion as he accelerates the rate of weatering and erosion through his economic activities to such an extent that the amount of weathering and erosion caused by human activities within few minutes (dynamite explosion) may be achieved by natural processes in thousands to millions of years. Thus man has emerged as a very potent modifier of the sediment cycle. Man's activities mainly land use changes through deforestation, expansion in agriculture, industrial growth, urbanization etc. have largely affected the rate of soil erosion, sediment load and thus the overall mechanism of the sediment cycle.

10

PLANT SYSTEM

Plants play very dominant role in the biosphere because these are primary producers in the biosphere and provide directly or indirectly food to all terrestrial and aquatic animals including man. The social groupings of plant species are called **plant community** of which plant is the fundamental basic unit. Plants directly receive and trap solar energy (light energy) and prepare their own food with the help of sunlight through the process of **photosynthesis.** Thus solar energy converted into food or chemical energy is transferred to different animals and micro-organisms through different trophic levels of food chain (chapter 8). Thus plants are intermediary between biotic and abiotic components of the evironment /ecosystem/biosphere. On the basis of importance and dominant role of plants in the biosphere the study of plants is given more significance. The study of plants has been developed as an important branch of geography which is called as **plant geography** which includes the study of classicification of plants, their spatial distribution, origin and development, dispersal and extinction and functions. The main functions of plants are to trap solar energy and prepare their food with the help of photosynthesis and to circulate and transfer energy and nutrients among the organisms of different trophic levels of the food chain. These aspects have already been discussed in the preceding 8th and 9th chapters.

10.1 VEGETATION AND PLANT COMMUNITY

The group or association of plants growing together in a particular habitat is caleld **plant community.** In other words, 'those plants which grow together in a particular habitat are referred to as a plant community, by which some thing more than a mere collection or assemblage is implied' (J. Tivy, 1982). 'A group of populations of different species living in the same local area and interacting with one another is called **ecological community** (B.D. Botkin and E.A. Keller, 1982). The plant community of a given habitat has three basic characteristics e.g. (i) a community consists of plants of two or more different species, (ii) a plant community consists of such species of plants which are ecologically related and can live and grow together in a particular habitat, and (iii) a plant community is well organised i.e. it has well developed composition and structure which are the result of continuous interactions between different plant species and between plant species and their physical evironment through time.

The association or group of plant communities of any region is called **vegetation.** In other words, 'alll the plants which grow together in any area form its **vegetation,** the character of which depends not just on different species present but on the relative proportions in which their members are represented' (J. Tivy, 1982). For example, two habitats may have similar floras but their vegetation may vary from one another and two havitats having different floras may have similar vegetation. For instance, if there are two similar habitats wherein both have grasses and sal trees but there is overwhelming dominance of grasses and sparse distribution of sal trees in the first habitat whereas the second habitat is characterized by dense sal trees and sparse distribution of grasses, the vegetation of the first habitat will be grasses whereas the vegetation of the second habitat will be sal forest (also see sub-section 6.6.2 (1)-plant system in chapter 6).

10.2 VERTICAL STRATIFICATION OF PLANT COMMUNITIES

Different species of plants are evolved in a habitat having favourable environmental conditions wherein different species of plant community grow together having different life-forms. The development of different species of plant community of a given region takes place through the processes of **adaptation, competition** and **natural selection.** This results in the development of various strata or layers between the soil surface or ground surface and the tree canopy. This vertical layering pattern or vertical stratification of plants is the result of competition among various species of plant community to get sunlight because it is the primary source of energy for photosynthis through which these plants manufacture their food. It is obvious that the availability of sunlight is mainly responsible for the development of vertical stratification of plants wherein the height of different species of plants varies significantly. On an average there are four vertical strata of plant community in a given region mainly in the deciduous forests of the temperate regions.

(1) **Dominant Layer** represents the topmost layer of the plant community (fig. 10.1) which is determined by the canopy of the largest trees. This uppermost stratum is also called **crown** or **canopy** which represents the highest limit of plant community in a given region. A secondary layer very often called as **co-dominant layer** is formed just below the crown or dominant layer by those large trees which are relatively shorter than the largest trees (fig. 10.1).

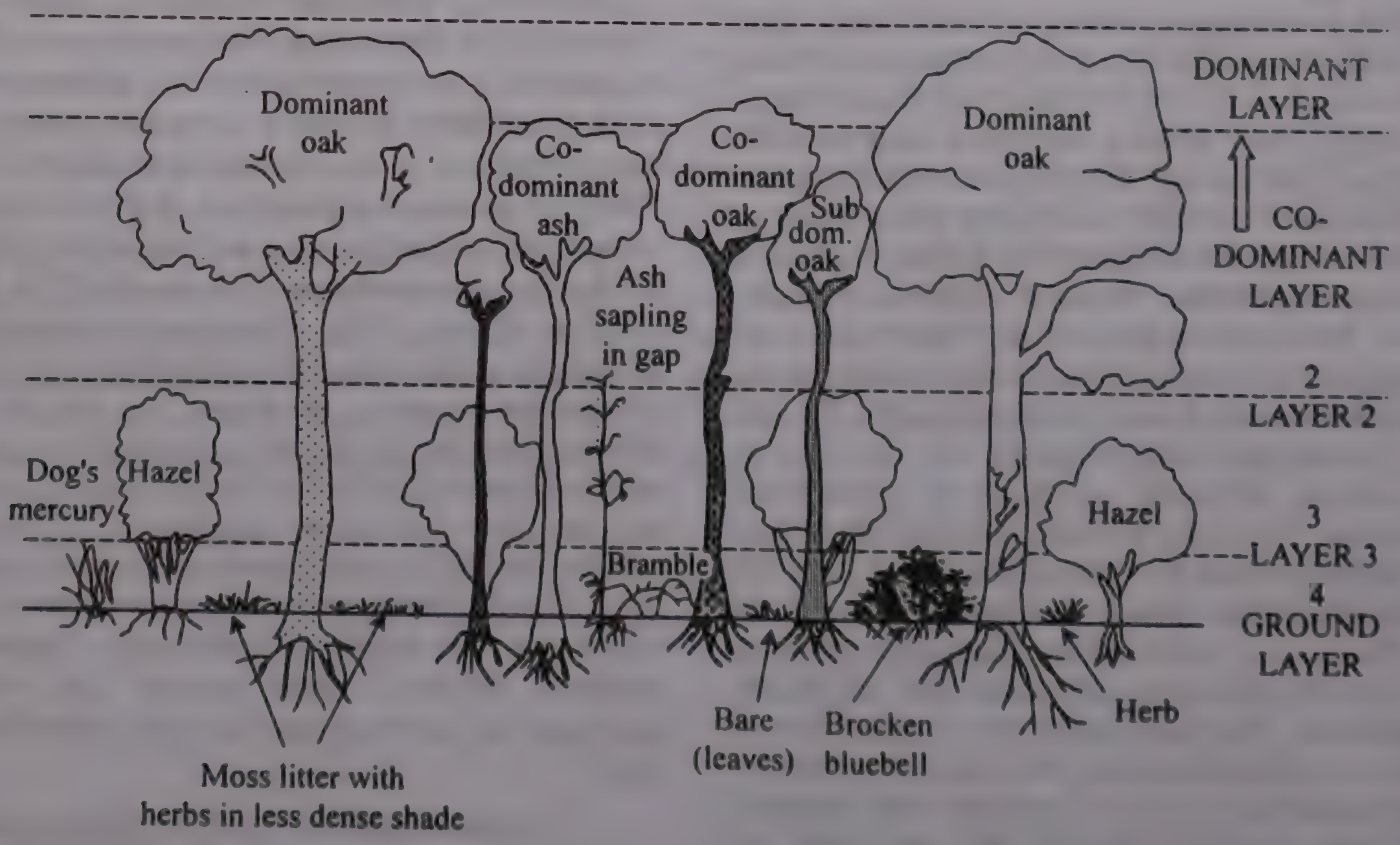


Fig. 10.1 : Vertical stratification or vertical structure of temperate deciduous forests (after J. Cousens, 1974). Additional examples of vertical stratification of other forests are given in the chapter on BIOMES (Chater 12).

(2) **Second Layer** is located below the dominant or crown layer and is represented by plants of shruby life-form. This is also called as **shrub layer.**

(3) **Third Layer** is formed by the herbaceous plants and is also called as **herb layer.**

(4) **Fourth Layer** represents mosses on the ground surface and is also called as **moss layer** or **ground layer** (strata).

It may be pointed out that the environmental conditions of each stratum or layer of the aforesaid vertical stratification of the temperate deciduous forests differ from the other stratum. The crown or the dominant or the uppermost stratum is completely open to sunlight and therefore it is fully affected by sunlight, wind and precipitatioin. Plants continously grow upward. As we go downward from the uppermost stratum (layer) through the second and third strata to the ground or fourth stratum there is gradual loss of sun light and decrease in the effect of precipitation, temperature and wind but there is gradual increase in moisture content (humidity). Thus various speciees of plant communties have to adjust with the changing environmental conditions from the uppermost stratum to the lowermost ground stratum. It may be mentioned that different plant species growing in different vertical strata of plant communities of a given region are fully adjusted with each other. If the topmost layer of the dominant species is removed through mass felling of trees, the structure of that particular plant community and the interrelationship between plant species of different strata will not only be disturbed but will be destroyed.

10.3 SUCCESSIONAL DEVELOPMENT OF PLANT COMMUNITY (BIOTIC SUCCESSION)

The natural process of replacement of one vegetation community in a given habitat by the other vegetation community is called **succession.** Succession simply means the entire process of directional and sequential change of either plant community (groups of plants adapted to a particular habitat) or the whole ecosystem through time. In simpler term, an **ecological succession** may be defined as the process of sequential devemopment of ecological community or ecosystem. The sequence of the development of vegetation community is called **sere.** In other words, the transitional stages of sequential changes from one vegetation community to another vegetation community are called **sere** which is complete when the succession of vegetation community after passing through different phases of changes culminates into equilibrium or mature condition. This phase of development of vegetation community is characterized by maximum growth and development of plants. Thus the vegetation community developed at the end of succession is called **climax vegetation, climax community,** or **climatic climax** (due to dominant control of climate on the evolution and development of vegetation). It is obvious that the last succession in the chains of successional changes of vegetation community becomes climax succession.

Phases of Biotic Succession

F.E. Clements (1916) has described five sequential phases in the successional development of vegetation community in a given habitat with available environmental conditions.

(i) Phase of **nudation** or the creation of bare area devoid of vegetation.

(ii) Phase of **migration** begins with the arrival of seeds into the newly created bare area.

(iii) Phase of **ecesis,** when the plant seeds are established in the newly created bare area and the seeds are germinated and plant growth continues.

(iv) Phase of **reaction,** when there is competition between the established plants on the one hand and interactions between plants and the physical environment of the habitat on the other hand.

(v) Phase of **stabilization,** when there is equilibrium condition of populations of plant species in harmony with the environmental conditions of local and regional habitats.

Types of Seral Stages of Succession

It is important to note that the development of different vegetation communities takes place in different habitats and therefore **seral stages** of vegetation succession are clasified into three types on the basis of types of habitats e.g. (i) **hydrosere** takes place in wet sites like swamps, lake shores etc., (ii) **xeric** or **xerosere** represents the successional development of vegetation on sand dunes of dry deserts, and (iii) **lithosere** takes place on bare rocks of the continents where excessive evaporation causes dry condition.

Factors of Biotic Succession

The development of vegetation community in any ecosystem or habitat is affected and controlled by the following factors :

(1) **Climatic factors** : Temperature, sunlight, soil-moisture, humidity etc. are the major climatic factors which affect the successional development of vegetation community. It may be pointed out that macro-climatic conditions of a particular region are not as much effective in the successional development of vegetation of that region as are the effects of micro-climatic conditions of the neighbourhood of the plants covering a few square metres of area.

(2) **Edaphic factors** include such soil properties which are important to plant life e.g. nutrient contents in the soils, soil texture, soil structure, soil solution, soil temperature etc. (see chapter 7).

(3) **Biotic factors** include the influences of living organisms of a given habitat on plant life of that habitat mainly the influences of animals in general and man in particular. Man is capable of destroying the whole of vegetation community of a given habitat within short period of time through his destructive activities. The competitions among plants for space, sunlight, water or energy also affect vegetation community in a given habitat.

(4) **Physiographic factors** include nature of ground, reliefs (mountains, plateaus, plains, faults), altitude, depths, slope angle, slope aspect etc.

(5) **Fire factors** include both natural forest fires through lightning and man-caused forest fires due to deliberate actions (e.g. jhuming cultivation) or inadvertent actions. Such forest fires destorty the vegetation community at a very large scale.

Types of Biotic Succession

The succession of vegetation community in any habitat of an ecosystem is classified into two types on the basis of changes in the environmental conditions of that habitat.

(1) **Autogenic succession** takes place when the changes in environmental conditions of a given habitat are effected by the vegetation itself.

(2) **Allogenic succession** takes place in a particular habitat wherein the changes in the environmental conditions of that habitat are effected due to variations in the abiotic or physical components of the environment or the habitat e.g. global climatic changes, rapid rate of siltation of lakes, ponds etc., accelerated rate of erosion of the region concerned, upliftment or subsidence of ground surface etc.

F.E. Clements (1916) has divided succession of vegetation community in two types e.g. (1) **primary succession**, and (ii) **secondary succession.**

1. Primary Biotic Succession

Primary succession refers to developmental sequence of vegetation in those bare areas where there were no vegetation and animals earlier. Such areas or sites may be newly emerged sea floor, cooled and solidified basaltic surfaces due to recent lava flows, exposed lake bed due to drying of water, newly formed sand dunes, flood plains formed by recent alluvia, heaps of debris accumulated by man, the areas of exposed rocks due to melting of ice from the glacial areas etc.

Stages of Primary Succession

The initial sites for the primary successional development of vegetation may be of various types having varying environmental conditons as referred to above but for convenience such site is being selected which is of bare rock surface and does not have any earlier vegetation for the explanation of primary succession of vegetation. Thus primary succession of vegetation on a bare rock surface having no prior vegetation and animals starts and is completed through the following stages :

(i) The initial plant-free site has relatively dry environment. It does not mean that the climate of this site is dry becuase the rocks of the conerned site are bare and are devoid of any plant and therefore the environment becomes relatively dry due to excessive evaporation though the climate may be even humid. The **pioneer plants** are established upon the bare rocks of the initial plant-free site. The initial pioneer plants include mainly algae and lichens because they easily stick to the bare rocks and can easily adapt to the environmental conditions of the initial sites whether these may be hot, dry or cold.

(ii) Dust particles blown by wind settle down in the concerned habitat. These dust particles are gradually deposited around algae and lichens. Some of the lichens secrete acids which react with the minerals of the rocks of that habitat resulting into dissolution of some minerals. This process starts the process of pedogenesis (soil-forming processes) and thin veneer of soil is formed in due course of time. The soil zone, though very thin in the beginning, is colonized by **micro-organisms.**

(iii) The formation of soils through rock weathering and soil-organisms continues and the thickness of soils continues to increase wth time. Consequently, a few soil-living animals like mites, ants, spiders etc. are evolved. This **'sere'** of successional development of plant community is characterized by more **soil living organisms,** sporadic plants and wide open areas devoid of any plant. This type of plant community is called **open community** or **pioneer community.**

(iv) **Secondary community** of mosses replaces the pioneer community of algae and lichens in due course of time. The mosses spread over the soils like thin sheets and thus soils are covered by the mosses. Consequently, the moisture content of the soils is increased because the moss cover retards evaporation. Now dense matting of mosses also provides organic matter to the soils and thus the soils are enriched by the addition of organic nutrients. Gradually and gradually seasonal and perennial grasses are developed along with new groups of animals like nematodes, spring-tails etc. which are able to obtain their food from the seasonal and perennial grasses. The gradual development of grasses covers the whole area of the concerned habitat and thus is developed a dense vegetation cover which changes and modifies the microclimates of the concerned habitat. The dense vegetation cover decreases ground temperature and sunlight at the ground surface but increases moisture content of the soils because evaporation of moisture from the soil surface is effectively decreased due to shade provided by dense vegetation cover. The **open community** is now changed to **closed community** (which means that no part of the concerned habitat remains without vegetation, in other words, whole area of the habitat is covered with vegetation). This is possible only when the environment of the concerned habitat is wet but if the environment of the concerned habitat is dry and the surface is of sandy desert, much area is still open and devoid of vegetaion.

(v) After the development of 'sere' of closed community there begins the competition among the plants for space, sunlight, water and nutrients. There may be two alternative routes of competition among the plants e.g. (a) If the plants of the concerned habitat are of the same species, there is competition for the aforesaid elements among the different members of the same species and only the fittest plants survive during the competition. Thus the principle of 'survival of the fittest' becomes effective in the community development of plants. Such competition is called **intraspecific competition** which means survival of the strongest plants and elimination of weaker plants but the preservation of species is maintined. (b) If there are more than one species in the concerned habitat, competition for getting space, sunlight, water and nutrients takes place among the individuals of different species wherein the strongest and most aggressive species establish dominance over the entire vegetation community. But if all the species of the concerned habitat are equaly powerful, there is maintained a balance of power among different species inspite of competition and the result is that all species are preserved and maintained. Such competition is called **inter-specific competition.** The phase (sere) of community development is dominated by herbaceous plants and thus by **herb community**.

(vi) With the march of time there is developed large shrubs in the concerned habitat and the herb community is dominated and replaced by **'scrub community'.** At this stage a very significant development takes place in that the seeds of flowering plants (phanerogams) are brought from the neighbouring areas to the concerned habitat by winds and give birth to trees in the otherwise shrub-dominated habitat. The canopy of these scattered trees is much higher than the stratum of shrubs. Thus this vegetation community upto this stage (sere) is mixed with lichens, mosses, grasses, shrubs and tree. This is called **forest community** and the sere of this successional development of vegetation community is called preclimax.

(vii) The final stage or 'sere' of the succesional development of vegetation community is characterized by the development of giant and very tall trees, the density of which increases rapidly and the whole of the concerned habitat is covered with dense and tall trees. The roots of such talll trees penetrate far deeper in the ground. The soil zone attains its maximum depth, and different horizons of the soils profiles are well developed. The soil zones are colonized by various micro-organisms which decompose the organic matter and help in the process of energy transfer. The vertical stratification of plant community is well developed. This final phase or 'sere' of the successional development of vegetation community is called **climax community, climax succession, climatic climax vegetation** etc. which represetns mature ecosystem.

The aforesaid example of primary succession of plant community is related to terrestrial ecosystem. The island of Krakatoa presents a fine example of primary succession about which well documented accounts are available. Krakatoa island located in the Sunda Strait between Java and Sumatra was adversely affected by violent volcanic eruption of central type in 1883 when 67 percent of the island sank and only 11 km^2 of the island remained above water but this too was covered by hot ash and pumice upto the depth of 30 to 60m. Thus the new surface created after the volcanic eruption was completely sterile but the newly formed surface was colonized by animals, micro-organisms and plants very rapidly because fully colonized islands with mature vegetation community were hardly 40 km away from the new habitat of Krakatoa island. Due to nearness of colonized islands some seeds were brought in by wind, some seeds were transported to the island by oceanic currents and some seeds were carried by birds. The island was again colonized by climax vegation within less than 50 years after the great volcanic eruption is 1883.

The sequences and stages of primary biotic succession of plant communities may be summarized as follows :

- development of pioneer plants like algae and lichens on plant-free bare rocky surfaces.
- pedogenesis (soil fromation) leads to the development and colonization of micro-organisms.
- development of soil-liviing organisms and open community of scattered plants with wide open areas devoid of any plant.
- development of secondary community of mosses and closed community of dense vegetation.
- dominance of herbaceous plants (herb community).
- development of forest community mixed with lichens, mosses, grasses, shrubs and trees.
- development of climax community of mature ecosystem.

2. Secondary Biotic Succession

Secondary succession refers to the developmental sequences of vegetation in those areas which had vegetation cover earlier but now have been rendered nude or bare due to destruction of vegetation (either partly or completely) either by (i) natural processes (like lava flow, prolonged drought, glaciation, natural widespread forest fires through lightning, severe storms, catastrophic floods etc.), or by (ii) human interferences (like intentional burning of vegetation, massive land use changes, mass felling of trees and overgrazing etc.). It may be pointed out that such disturbed ecosystems or habitats still contain mature soils and some original vegetation and therefore the initial stage or **'sere'** of secondary succession of plant community is quite different from the initial stage or 'sere' of primary succession which starts on a bare rocky surface, having no earlier plants and animals. The total time required for the development of **climax vegetation** or **climax succession** in the secondary succession is much less than the time taken for the development of primary succession.

An example of secondary succession may be given from the hill areas of north-east India where **jhuming cultivation** (shifting cultivation) is a common practice. Under this cultivation, first forest is cleared from small areas through burning and then the soil is cultivated for agricultural crops for a few years. When the soil loses its fertility, that area is left out and new areas are cleared of vegetation for cultivation. The abandoned area or the old clearance is again colonized by vegetation through various stages and it attains **climax vegetation** (climax succession) in a short period of time (a few years), because the sequence of secondary succession is more rapid than the primary succession due to availability of mature soils.

When the vegetation community of any region is disturbed before reaching its 'climax sere' by human interferences (through slow but long-term activities like deforestation or burning of vegetation etc.), the resultant vegetation is called **sub-climax vegetation.** When the distrubances in the successional development of vegetation continue for long time, stages of normal sere of the development of vegetation do not take place but these 'sere' are deflected by those factors which bring in disturbances in the successional development of vegetation. The vegetation developed during the **deflected sere** persists so long as the factors responsible for the disturbance remain active. Such **deflected climax** is called **plagioclimax** and its various stages are called **plagiosere**. After some time if the factors causing disturbances in the succesional development of vegetation community cease to operate or become ineffective, then the environmental conditions of the concerned site or habitat are changed, with the result new environmental conditions of the habitat are unable to support and preserve the **plagioclimax vegetation.** Thus new vegetation develops under new changed environmental conditions in place of plagioclimax vegetation and the successional development of vegetation community takes place under normal sere.

To my mind the disturbance caused by natural factors or by human interferences in the normal sere of the primary succession of the vegetation community should be termed as the **interruption of community** and the vegetation community developed during the interruption should be called as **interrupted communiy.** It is believed that the present agricultural areas were previously covered with dense vegetation cover. At a much later date, man interrupted the normal development of vegetation communities and thus deflected the normal sere of the primary succession. If the cultivation of such areas (e.g. the Ganga Plain of India or the Mississippi Plain of the U.S.A.) is stopped, the development of normal sere of vegetation community would restart and the climax succession of the development of vegetation community would be established.

. Climax Vegetation

Climax vegetation (climax community) is the nd point or final phase of the process of succession sequential development) of vegetation community, rimary succession or secondary succession, in any cosystem or habitat. In other words, the vegetation ommunity developed at the last stage of biotic uccession is called **climax vegetation** which is ndicative of a mature ecosystem wherein the ominant vegetation is in equilibrium with the nvironment. With the attainment of climax vegetation or mature ecosystem **biomass** increases to maximum but net community production decreases and food chain becomes highly complex and thus it changes to food web.

The attainment of the climax and its nature have been explained differently by various scientists. Two theories have been put forth about the nature of the **climax** e.g. (i) monoclimax theory, and (ii) polyclimax theory.

1. Monoclimax Theory

The monoclimax theory put forth by F.E. Clements (1916, 1936) states that regional climate is the dominant control factor of climax vegetation. In other words, the form of vegetation of any region during each stage or sere of the successional development of vegetation community is determined by the climate of that region. It is obvious that the form of vegetation is in accordance with the climate of region concerned. This is called **uniform climax condition** and the vegetation developed during such uniform climax condition is called **climatic climax vegetation.** If all the successional phases or 'sere' of the development of vegetation community of a region are unable to attain uniform climax condition in harmony with the climate of that region within a reasonable time, the end product of the succession is called **subclimax.** With the attainment of uniform climax condition and climax vegetation the ecosystem becomes mature, micro-level changes in the environment do not occur, species become competent enough to reproduce their offsprings in their own place of living, the intrusion of any external aggressive colonists becomes impossible in the habitat of mature ecosystem, there is progressive increase in the complexity and diversity of communities, the ecosystem reaches the state of stability and no significant changes occur in the ecosystem (in the absence of human interference only).

2. Poly-Climax Theory

Poly-climax theory states that plant community of each ecosystem or habitat is not always in equilibrium with the climate of that habitat. In a few habitats or regions plant communities do not always undergo the process of successional changes. In such cases the climax vegetation is not determined by the climate of the region concerned but is determined by soil types or topographic characteristics, or natural forest fires, or destructuve and constructive activities of man etc. The theory further states that many climax communities may be developed in any climatic region. There are specific examples of many climax communities in a single climatic region. In other words, there may be different habitats because of various combinations of local or micro-climate, reliefs, rocks, biotic factors etc. in a single climatic region and the different climax communities may be developed in different habitats of a given region inspite of the fact that the macro-climate of all the babitats of a region is the same.

Types of Climax

A.G. Tansely has defined the climax on the basis of main dominant factor which controls the maximum growth of vegetation of any habitat. According to him the climax thus should be identified on the basis of the most dominant controlling factor e.g. (i) **climatic climax,** when climate is the most dominant factor of all the controlling factors, (ii) **edaphic climax,** when soil is the most dominant factor, (iii) **relief-climax** (relief being the most dominant factor), (iv) **anthropogenic climax** (human interferences being the most dominant factors), and (v) **biotic climax** (biotic factors being the most dominant factors).

According to R.H. Whittaker no **absolute type of climax** is possible if the successional development of vegetation community is determined by one or more than one factors which control the development of vegetation in any region, rather the **climax community** is the result of combined effects of all the factors of a given region which control the development of vegetation.

Though there is no unanimity among the botanists and the ecologists about the concept of **climax** but all the scientists agree to the point that the **'climax'** is indicative of the stability of vegetation community of a given ecosystem or habitat. Thus the 'climax' denotes dynamic equilibrium of vegetation community which reveals equilibrium not only betweeen vegetation community and its physical environment but also between all organisms (plants, animals and micro-organisms) and their physical environment.

10.3 EVOLUTION OF PLANTS

Plant evolution means the origin, growth and development of plants through time. Thus the evolution is the indicator of historical development of plants. The following are the important processes and mechanisms which determine the nature of evolution of plants in any region :

(1) **Variation** is common feature of all plant species because there is a wide range of variation and diversity in the plants. Even there is much variation in the different populations of a single species in terms of their height, size, shape and size of leaves, number, colour and structures of flowers etc. Even there is variation among the offsprings of the same parents. Every plant inherits the qualities of its parents and these inherited qualities help in the growth and development of plants. These inherited qualities get modified by the environmental conditions during the growth and development of plants. This inheritance of the qualities of the parents by their offsprings, which maintains the similarity of their genetic constitution, is called **genotype** while the modified appearance of the plant due to modifications in the inherited genetic qualities of the plants by the environmental conditions is called **phenotype.** In fact, the phenotype represents the observable characteristics of an organism produced by the interactions of genes and environment.

1. Processes of Evolution

There are two major processes of evolution of species e.g. (i) the proces of **selection,** and (2) the process of **isolation.** The process of selection is of two types viz. (i) **natural selection,** and (ii) **artificial selection.**

(1) **Natural Selection :** Charles Darwin (1859) postulated the principles and mechanisms of evolution of species by the process of 'natural selection' wherein the heritable variations in the populations (here population means a community of individuals of sexually-reproducing species) form the basis of evolution of species. The principles of natural selection will be elaborated in the next section namely origion of species.

The process of natural selection simply means that a few of the advantageous qualities inherited from the parents of species by a few populations of that species are such that these qualities enable a few individual members of that species to survive in their environment and to become adapted to the environmental conditons. On the other hand, some individual members of the species lack in the advantageous qualities because these could not be inherited by them from their parents. In such cases the individuals, which possess the advantageous qualities, which are useful for their adaptation to their environmental conditions, eliminate those plants which do not possess those advantageous qualities.

(2) **Artificial selection** occurs through human activities when he creates new environment. For example, man creates new seeds to increase the crop-productivity through artificial measures such as cross-pollination and hybridization. Such newly created hybrid seeds are disease and pest-resistent and are capable for their adaptation to various types of soils and climate because they have sufficient tolerance capacity to withstand adverse environmental conditions. This process of artificial selection carried out by man creates new hybrid and high-yeilding seeds on the one hand and eliminates several naturally occurring seeds on the other hand. This process may be beneficial for mankind at present because it may solve the problem of short supply of foodgrains through increased production but it may prove disastrous in coming future when all the natural plants of food crops will disappear from this planet earth.

(3) **Isolation** plays an important role in the evolution of plants. The process of isolation is related to the **reproduction** of morphologically differentiated populations of species and thus this is also called as **reproductive isolation.** The process of isolation stops the exchange of genes between different members of species. This reproductive isolation is caused due to a variety of barriers which may be grouped in two categories e.g. (i) external barriers (factors), and (ii) (ii) internal barriers (factors). External factors operate from outside the plants and prevent cross-pollination between different populations of species of plants. The external factors (barriers) include (i) spatial or geographical isolation, (ii) ecological isolation, (iii) seasonal isolation, (iv) mechanical isolation etc.

The **geographical isolation** is caused due to distance factors or distance barrier. When the members of one species of plants are separated from one another by the presence of large physical (relief) barriers (e.g. vast desert, seas and oceans, extensive mountains etc.), cross-pollination or cross-breeding does not take place.

The **internal factors** operate from within the tissues of the plants. These internal factors prevent hybridization even after cross-pollination has taken place among the different populations of species. Thus the isolation caused by internal factors prevents inbreeding among the members of one species and consequently several sub-species of the main species are evolved and developed.

2. Origin of Species

The evolutionary development in the plant kingdom takes place through the processes of mutation, genetic recombination, natural selection, isolation etc. but it is the process of isolation which is responsible for the origin and development of new species through reproduction. The process, which is responsible for the origin of species, is called **speciation.** The speciation takes place in two forms e.g. (i) **gradual speciation,** and (ii) **abrupt speciation.**

Gradual speciation is also called as **geographical speciation** wherein initial breeding and reproducing plants are evolved in any region having homogenous environment. The number of such plants gradually increases and their habitat also expands (as new plants colonize more and more areas). Consequently, the plants of the concerned environment intrude in the adjoining area of different environment. These intruders or newcomer plants develop their own subpopulations or subgroups amid already developed plants of the adjoining areas. Subspecies are evolved through the selective influences of these newly developed subpopulation.

The newely developed subspecies of plants are, at much later date, isolated by distance factor. In other words, these newly developed subspecies of plants are separated from each other and from the members of initial species to which they originally belonged. Such distribution of species is called **allopatric distribution** which gives birth to new species of plants because geographically isolated members of the same species are not capable of interbreeding and producing strong offsprings. Such isolation which prevents interbreeding among the populations of the same species is called **reproductive isolation.**

A few members of this newly developed species, at later date, come back to their original place which is still occupied by their parents. This so happens when the environmental conditions of the habitat of newly evolved and developed species change. Though there is variation in the characteristics of the populations of the original species of the initial habitat and the populations of newly developed species but there is still some similarity between the initial populations of the original habitat (parent species) and emigrant and reinhabited members (which now have become the members of new species). Such distribution of plants is called **sympatric distribution** but the plants of such distribution cannot merge among themselves because of reproduction barriers. 'However, reproductive contacts may be formed between populations which have previously been isolated geographically as a result of migration of one into the area of the other' (P.A. Furley and W.W. Newey, 1982). However, when two species of dissimilar habitats invade the territory of each other, cross-breeding becomes possible and the resultant hybridization gives birth to new species.

(2) **Abrupt speciation** is the process of sudden evolution of new species. This so happens when there is sudden change in the number of chromosomes in the plants.

Mutation is another process of speciation wherein the spontaneous evolutionary change gives birth to new species.

(1) **Darwin's Theory of Evolution** : The Darwinian theory of origin of species, propounded by Charles Darwin in 1859, is related to the concept of progressive evolution of species (gradual speciation). Charles Darwin postulated the principles and mechanisms of the evolution of species by the process of **'natural selection'** and **'survival of the fittest'**. The following are the main principles of natural selection (based on H. Robinson's interpretation of Darwinian theory of the origin of species) as advanced by Charles Darwin :

- There are heritable variations in the individual species. Though each heritable variation is small but it is very significant because it forms the very basis of evolution of species.
- Heritable variations provide certain characteristics which become advantageous to some individuals to become more efficient and better able to survive in their environment for the struggle of their lives.
- Such advantageous characteristics conferred on an organism may provide better chance of survival and reproduction.
- When these advantageous characteristics are passed on by the organisms to their offsprings, the succeeding generations become superior and further efficient in the struggle for existence and survival.
- The individuals of species, which lack the advantageous characteristics to stand up to their environmental conditions in their struggle for life and existence, are most likely to be eliminated by competition from the better equipped superior members (which have acquired advantageous characteristics of their species).
- During the struggle for existence between organisms, the winner leads to evolution of species and the loser leads to extinction. This so happens when the struggle takes place between closely related species.
- The process of natural selection (as referred to above) and adaptation of environmental conditions lead to gradual modification and diversification of species over long period of time. Such variations in species incease progressively with each succeeeding generation of species and evolution of species continues.

(2) **D. Vries' Theory of Evolution** : De Vries challenged the Darwinian concept of **progressive evolution of species** on the ground that some times the offsprings differ from their parents so markedly that a new species is evolved within a single generation. The process of **spontaneous evolutionary change** is termed as **mutation** which is believed to introduce inheritable variations in a species. Such inheritable variation can be spread by inter-breeding. T. Dobzhansky (1950) has presented the following basic elements of mutation :

- 'The mutation process furnishes the raw materials of evoltuion'.
- Numerous gene patterns are produced during the process of sexual reproduction.
- 'The possessors of some gene-patterns have greater fitness than the possessors of other (gene) patterns in available environments.'

- The frequency of superior gene-patterns is increased by the process of natural selection while the inferior gene patterns are suppressed.
- 'Groups of some combinations of proven adaptive worth become seggregated into closed genetic system, called species'.

(Quoted by C.C. Park, 1980)

It is obvious from the aforesaid description that T. Dobzhansky is of the opinion that no organism is changed by natural selection but natural selection definitely provides an opportunity for the organisms to attain the quality of adaptive transformation so that it can react to a change in the environment. Plant kingdom (and also the animal kingdom) of any habitat or the whole biosphere is evolved and developed by different processes and mechanism of speciation. The initial unit or link of plant evolution is species. Different species form plants of higher orders. Species differentiation gives birth to genus (plural-genera). The processes of adaptation, selection, isolation, mutation etc. are responsible for the formation of 'family' which includes several 'genera'. The process of speciation continues and the gradual evolution of species culminates into the formation of successive higher orders of plants namely **'order'**, **'classes'**, **'phylla**, and several phylla form **'plant kingdom'.**

10.4 EVOLUTIONARY HISTORY OF THE WORLD PLANT COVER

The present plant cover of the world is the result of gradual evolutionary phases of plants through past geological periods of the earth's history. The study of the evolutionary history or the historical development of vegetation community right from the origion of the first plant to the present day distribution of plant species and vegetation communities is carried out on the basis of the analysis and interpretation of vegetation fossils preserved in the sedimentary rocks. Thus the study of the evolutionary history of plant cover falls under the domain of palaeobotany. The various aspects of the study of the historical development of plants and vegetation community e.g. discovery, identification, interpretation and time correlation of vegetation fossils preserved in the sedimentary rocks with the geological formations need highly specialized skills and these are carried out in plaeobotany. The discussion of these aspects mainly the techniques of reconstruction of the evolutionary history of the world plant cover is not desirable for the students of geography. We need only the results of these techniques which some times give misleading and confusing inferences. The views of palaeontologists regarding the interpretation of evolutionary changes of the organisms (both plants and animals) on the basis of available records of fossils of plants and animals preserved in the sedimentary rocks are grouped into two schools of thoughts as elaborated by S.J. Gould (1971).

(i) **School of phylectic gradualism** states that the evolution of all branches of the whole plant and animal kingdom takes place slowly and side by side over long period of time. Some times a few groups evolve more rapidly than the other groups. This type of evolution is called **gradual speciation or geographical speciation.** This process of speciation has already been discussed in the preceding section.

(ii) **School of punctuated equilibrium** believes that the organic world is in the state of equilibrium and there is gradual evolution of species but some times the equilibrium is distrubed or interrupted and thus there are short periods between two periods of stability or species equilibrium. These periods are characterized by sudden happenings and catastrophes when there is abrupt and sudden evolution of species. This process of the speciation is called as **abrupt speciation.**

On the basis of records of fossils discovered from the sedimentary rocks D.V. Ager (1976) has concluded that fossil records do not indicate gradual successive evolution of the organisms but these records show that evolution has been episodic in nature wherein one group of species suddenly advances at the cost of the other group of species.

The historical evolution of the plants can be traced through the geological periods as follows :

(1) **Evolution of Heterotrophs :** Evolution of organisms on the earth's surface begins from the **pre-cambrian period** when probably the first life in the form of single celled or unicellular microscopic organisms resembling the present-day cocoid or spheroid bacteria, was evolved in aquatic environment. These early organisms were anaerobic heterotrophs (these organisms did not use oxygen because at that time there was no oxygen in the environment). It may be pointed out that there were

no autotrophs in the beginning due to absence of photosynthesis. Thus the initial organisms were heterotophs which depended for their food on non-biologically produced organic food. The early organisms used to live in water and derived their food in the form of diluted nutrients in liquid form. As regards the origin of non-biologically produced organic food, it is believed that a few organic compounds might have been synthesized from the mixture of some simple substances like methane, ammonia, water vapour etc. by ultraviolet radiation (it may be remembered that in the beginning of the evolution of organisms there was no ozone layer because of the absence of atmospheric oxygen and hence most of ultraviolet radiation reached the earth's surface) or electrical discharges.

(2) **Evolution of autotrophs :** It is believed that the initial heterotrophic organisms might have given birth to autotrophic plants which could have become able to manufacture their food themselves. The initial autotrophic organisms included purple bacteria, blue-green algae and green algae. It is important to note that like initial heterotrophic organisms initial autotrophic plants were also originated in water areas. These aquatic plants are supposed to have formed oxygen through biological processes. The oxygen, thus formed, was gradually diffused in the atmosphere and hence new aerobic organisms (organisms which use oxygen) were evolved. The gradual concentration of oxygen in the atmosphere resulted into the formation of ozone gas ($O_3 = O_2 + O$) which controlled the temperature of the lower atmosphere and the earth's surface by absorbing ultraviolet solar radiation. This resulted in the evolution and development of several aerobic complex multi-cellular plants and animals. It is believed that about 600 million years ago the atmospheric oxygen was about 3 percent of its present level in the atmosphere. Even this meagre amount of initial oxygen enabled a few multi-cellular organisms like sponges, corals, worms, shellfish and the ancestors of vertebrates to evolve and develop on the earth's surface.

(3) **Evolution of land plants :** It is believed that the origin and colonization of plants on the land surface began in late **Silurian** and **Devonian** periods when the first terrestrial green plants were evolved from the aquatic red and brown algae. During this period the landmasses were characterized by dry environment and the first green land plants were such that they could adjust with the dry environment. Rhynia and cooksonia are supposed to be the first plants to evolve on the land surface. The early land plants were characterized by vascular system, xylem, cuticle, stem-like green axes, stomata and terminal sporangia.

(4) **Evolution of vegetation communities :** During the beginning of **Devonian period** several new species of flora were developed and the first representative plants of the modern club-mosses and the ancestors of horsetails were exclusively evolved during early Devonian period. The first tree-like plants were evolved during middle and late Devonian period (e.g. large arborescent lycopods, tall horsetails etc.). Lycopods and horsetails became extinct in their original form but they could persist in transformed form like herbaceous plants. Ferns were evolved from the spores hidden in the earlier plants. By the end of Devonian period the flora attained a uniform character because of the development of vegetation in uniform climatic conditions and the vegation communities were transformed into forests.

(5) **Carboniferous flora :** All the landmasses continued to be united in the form of **Pangaea** upto **Carboniferous period.** The disruption of Pangaea and drifting of its broken landmasses had a great influence on the development of world flora. Though the breaking of Pangaea and continental drift have been validated on the basis of plate tectonics (which is based on two convincing evidences of palaeomagnetism and sea-floor spreading) but there is no unanimity about the time of disruption. Most of the scientists believe that Pangaea was disrupted during **Jurassic period** while some consider the disruption of Pangaea in the **Carboniferous period.**

It is believed that Pangaea consisted of two big landmases e.g. **Laurasia** (including Asia, Europe and North America) and **Gondwanaland** (including S. America, Africa, India, Australia and Antarctica). The northern segment of Pangaea (Laurasia or Angaraland) was characterized by the spread of dense luxuriant forests of tall arborescent plants during Carboniferous period. The vegetation included several genera of giant club-moses (lepidodendrum and sigillaria), cone-bearing plants having the height of more than 30m, the giant horsetail plants, ancestral forms of modern coniferous trees etc. which developed within swampy littoral habitats. These vegetations were buried under sediments and compressed and ultimately were converted into peats and coals. Most of the coal formations of North America and Western Europe belong to the Carboniferous period.

There was a global climatic change during Carboniferous period when most of Gondwanaland was covered with ice sheet and thus pre-Carboniferous ice Age vegetation of Gondwanaland, which was similar to the vegetation of Laurasia or Angaraland, was drastically changed. The deglaciation of ice sheets resulted into the origin of new sets of climatic conditions over Gondwanaland e.g. cold and humid temperate climates. During this period the **glossopteris flora** covered very extensive area of Gondwanaland. The remains of glossopteris are still found over the members of the Gondwanaland e.g. South America, Africa, India, Australia and Antarctica.

There was substantial change in the vegetation of Laurasia (Angarland) during late Carboniferous and Permian periods and consequently three main types of vegetation were developed e.g. (i) Eumerican flora in the western part of Laurasia (present north-eastern North America and Western Europe); (ii) Angara flora in modern Siberia and, (iii) Cathysian flora in S.E. Angaraland (modern China and S.E. Asia).

(6) **Mesozoic flora** : There was a large scale change in the climate, plant and animal life during **Mesozoic era** (which includes Triassic, Jurassic and Cretaceous) mainly due to disruption of Pangaea and large-scale drifting of continents and ocean basins. First, Pangaea was broken into two big landmasses known as Laurasia or Angaraland and Gondwanland. These were separated by Tethys Sea. These two landmasses were further disrupted into many parts which drifted in different directions to acquire their present position.

Dry climatic conditions prevailed over major areas of the northern landmasses during **triassic period** with the result most of the vegetation developed during Carboniferous and Permian periods was replaced by sparse vegetation of desert climate. Many species of dense forests of Carboniferous and Permian periods disappeared and became extinct but plant-eating dinosaurs could survive because of the availability of their food from cycads, conifers, ferns and horsetails which also could survive because they become successful in adapting themselves with new environmental conditions.

Jurassic and **Cretaceous** periods provided ideal climatic conditions for the development of a variety of plants and animals. Sub-tropical humid climate developed over major areas became most favourable for evergreen forests which included conifers, ginkgos, and cycads during Jurassic period.

The world flora underwent a tremendous transformation because of the emergence of flowering plants (phanerogams) during Cretaceous period. The evolution of **flowering plants** (both angiosperms and gymnosperms) was so rapid and abrupt under episodic events that they soon changed into dense forests. This sudden spread of dense forests of flowering plants resulted into marked decrease in the number of earlier species and their populations, because flowering plants became fittest and most dominant of all earlier plants. These plants included oak, poplar, sycamore, maple, ash and species of modern tropical trees e.g. breadfruit, fig, palm etc. These forests were characterized by dense undergrowth of shrubs and small trees which included laurel, dogwood, holly etc., and herbaceous plants. Thus the vegetation community was well organized by the end of Cretaceous period and the stratification was well developed e.g. top layer (stratum) of tall flowering plants, second layer of shrubs, third layer of herbaceous plants and fourth or ground layer of mosses and lichens. The following reasons have been suggested by the palaeobotanists to account for the abrupt evolution of flowering plants and their dominance over other (earlier) plants.

The **Jurassic period** was characterized by relative stability of environmental conditions but the Createceous period was punctuated by several events of earth movements (e.g. formation of mountain ranges, volcanic eruption and massive lava flows, faulting etc.), sea level changes resulting into transgression of seas on the continental margins and climatic changes. All these events resulted into the formation of new habitats having varying environmental conditions. The flowering plants possessed enormous capacity for their adaptation and adjustment to a variety of environmental conditions. Cosequently, the flowering plants fully exploited the new physical conditions of newly created habitats as they were quickly adjusted and adapted to new but varied environmental conditions. This resulted into rapid colonization of the earth's surface by flowering plants.

Flowering plants and insects were evolved together (side by side) through the process of mutualism. Thus the insects helped in crosspollination among the flowering plants which resulted in the genetic and ecological diversification which ultimately gave birth to the evolution of new species of flowering plants.

The capability of flowering plants to adapt and adjust with varying physical conditions enabled them to develop a great variety of lifeforms and habit which allowed a great variety of species of flowering plants to share and exploit the same habitat. This process resulted into the formation of different vertical strata or layers of plants communities.

(7) **Tertiary flora** : Though there is a lot of controversy about the exact place of the origin of flowering plants but the western part of Gondwanaland is generally considered as the birth place of flowering plants. From this part of Gondawanaland flowering plants were dispersed to other places. Large-scale global orogeny during Tertiary period (origin of Alpine mountains like the Rockies, the Andes, the Allps, the Himalayas etc.) and related climatic changes, glaciation of major parts of North America and Eurasia (**Pleistocene glaciation**) during Quaternary period, frequent changes in climate and sea levels because of sub-glacial and interglcial periods etc. have largely affected the life-forms and patterns of vegetation at global and local scales.

Summary of Historical Evolution of Plants

The detailed description of historical evolution of land plants, as given above, may be summarized as follows:

- Heterotrophs were evolved during pre-Cambrian period. These organisms depended on non-biologically produced organic food.
- Initial heterotrophic organisms gave birth to initial autotrophic organisms such as purple bacteria, blue-green algae and green algae during pre-Cambrian period.
- Origin and colonization of plants on land surfaces began in Silurian and Devonian periods.
- By the end of Devonian period the land flora attained a uniform character because of development of vegetation in uniform climatic conditions and the vegetation community was transformed into forests.
- During Carboniferous period glossopteris flora covered very extensive area of Gondwanaland. There was substantial change in the vegetation of Angaraland during Carboniferous period and consequently 3 main types of vegetatin developed e.g. (1) Eumerican flora in the western parts of Laurasia (present north-eastern North America and Western Europe); (2) Angara flora in modern Siberia, and (3) Cathysian flora in S.E. Angaraland (modern China and S.E. Asia).
- Most of the vegetation developed during Carboniferous and Permian periods over northern landmasses were replaced by sparse vegetation due to onset of dry climatic conditions during Triassic period.
- World flora underwent tremendous transformation during Cretaceous period due to emergence of flowering plants (phanerogams) which formed dense forests.
- The onset of monsoon climate during Tertiary period gave birth to the development of monsoon deciduous forests.
- Large-scale global mountain building during Tertiary period, related climatic changes, glaciation of major parts of North America and Europe during Quaternary period, frequent climatic and sea level changes due to deglaciation largely affected the life forms and patterns of vegetation at global, regional and local scales.

10.5 DISPERSAL OF PLANTS

Dispersal of plants refers to migration and spreading of plants from the places of their origin due to a host of factors. The present-day distribution of world vegetation communities is the result of gradual dispersal of plants through ages of geological history. The study of dispersal of plants includes the consideration of nature and factors of dispersal, patterns of dispersal in historical perspective, role of man in plant dispersal etc. These aspects are eleaborated below :

1. Nature and Factors of Dispersal

The present-day distribution of plants over the globe is the result of migration of plants over time into ecologically suitable areas. The spread or migration of plants takes place mainly in two ways e.g. (i) through **vegetative propagation,** and (ii) through **seed dispersal.** Since plants do not have mobility like animals, and hence plants spread or dispersal through vegetative propagation is exceedingly slow process and the new shoots which come out from the parent stocks do not acquire the genetic variability of seeds. Thus the plants coming out from the shoots of the parent stocks are not able to adapt to the variations in habitat where they reach through the gradual process of spreading.

Thus the dispersal of plants becomes effective through external factors mainly through the dispersal of seeds. The following factors determine and control the nature of seed dispersal and therefore dispersal and migration of plants :

(1) Properties of seeds,
(2) Agents of seed transportation,
(3) Speed and distance of dispersal,
(4) Geographical barriers,
(5) Tolerance factor,
(6) Continental drift, and
(7) Anthropogenic factor (role of man).

(1) Properties of Seeds

The properties of seeds which help in the process of seed dispersal include the following :

- The properties of seeds to stay up in the air while carried away from one place to another,
- The properties of seeds of sticking to the bodies of carriers (animals),
- The properties of sticking to the feathers and feet of birds,
- Property of floating in the waters,
- The ability of seeds to germinate and establish themselves as plants successfully in new habitats having different environmental conditions,
- Number and size of seeds and the frequency of their reproduction etc.

(2) Agents of Seed Transportation

The main agents of seed-transportation are **wind, ocean currents** and **animals** including **man** who transport seeds of various sorts in varying amounts in different ways. **Wind transports** seeds mainly in suspension from one place to another place. Smaller and lighter seeds are more efficiently transported by wind but such seeds are susceptible to high rate of mortality. **Birds carry** such seeds which stick to different parts of their bodies. Birds are very effective carriers of seeds because they can transport seeds to great distances. Besides, seeds which are kept in the stomach of birds are also dispersed when the birds release them as wastes. There are certain limitations of seed dispersion by birds i.e. only smaller seeds are carried away by birds, there is high rate of mortality of seeds carried by birds because if seeds are transported to such areas after covering long distances where environmenal conditions are not favourable for the germination of newely brought seeds they may die. **Other animals transport** seeds through their bodies when seeds are stuck to different parts of their bodies. The nature of seed dispersion by animals depends on the nature of their mobility, slow or rapid, daily, seasonal or annual etc. **Water transports** seeds and disperse them through its various types of movements e.g. sea waves, tidal currents and oceanic currents. **Man** has now emerged as the most potent and effective carrier of seeds because he is capable of increasing the speed and range of seed dispersal to the greatest extent.

(3) Limiting Factors of Seed Dispersal

There are certain factors which limit and restrict the dispersal of seeds e.g. **distance factor, geogrphical barriers, speeed factor** etc.

- Smaller and lighter (in weight) seeds are more efficiently transported to greater distances but they are susceptible to high rate of mortality,
- Larger seeds are difficult to be dispersed but these have low rate of mortality because they have greater chance of survival for long time due to greater food reserve contained by them;
- The size and number of seeds produced by different plants also affect and control seed dispersal. For example, annual plants produce large quantity of small seeds which can be easily transported to greater distances while many perennial plants produce few seeds but of large size. Such seeds are transported and dispersed as elaborated above.

- Oceans and seas are the most formidable limiting factors of seed dispersal because these are so extensive in size and become so enormous barriers that these are not likely to be crossed over by any means of seed dispersal. The most significant carriers of seeds through the oceans are the ocean currents which take very long time to transport them from one end of the land to the other end. On the other hand, it is very likely that seeds will perish during their long journey of water because there ae very few seeds of land or fresh water plants which can withstand the long period of their immersion in the oceanic saline waters. Similarly, extensive high mountains and extensive deserts are effective formidable barriers for the dispersal of seeds.

(4) Tolerance Factor

The tolerance factor plays more important role in the dispersal and migration of plants than the rate of seed production and the efficiency of transporting agents of seeds because ultimate success of seed dispersion depends not only on the ability of seeds to germinate in new environment of the habitat to which they have been transported but also on their ability to establish in new habitat and to adapt to new environment. The more the tolerance limit of plants to adapt and adjust to new environmental conditions of new habitat, the more is the chance of their survival and greater opportunities and possibilities of their distribution and expansion in extensive areas.

(5) Continental Drift

Continental drifts are also helpful in the dispersal of plants at global scale. The distribution and dispersal of flowering plants (phanerogams) developed during Cretaceous period can be explained in the light of continental drift. The presence of glossopteris vegetation in South America, Africa, Australia etc. could be possible due to continental drift. This aspect will be detaield out in the succeeding section (10.6).

(6) Role of Man in the Dispersal of Plants

Man has changed and diverted the direction of evolution of plants and animals, has accelerated the rate of reproduction, breeding and evolution and development of different populations of organic communities. He has intentionally created and evolved new species of plants and animals through the process of **'artificial selection'**. He has introduced new plant species through **'cross-pollination'** among different types of plants and has encouraged **'vegetative propagation'**. Man has developed new species by creating habitats of new environments.

Man has affected the dispersal, distribution, and redistribution of plants and animals and vegetative propagation through the following methods :

- Through his destructive activities e.g. deforestation for domestic, argicultural and industrial purposes, forests fires etc.
- Through the discovery and development of new types of vegetation and their establishment in suitable habitats.
- Through the removal of plants from their native places and their transplantation in other areas.
- Through agricultural practices.
- Through changes in the habitats.

Man has created new habitats for his own benefits by changing and modifying the local physical environment called as **hybrid habitats** which have two types of locations e.g. (i) near the camp-sites (this was in practice during pre-historic period), kitchen garden, city parks and national parks etc., and (ii) newly created areas for the construction of roads, rails, factories and for agriculture. Such areas are created through land use changes mainly through mass felling of trees or extensive deliberate forest fire. There is very fast rate of growth of plants desired by man in such disturbed or hybrid habitats because there is no competition among the desired plants and other plants as unwanted plants have been eliminated.

It is believed that the first domestication of plants of food crops was started in the north-western part of South America and S.E. Asia. That is why C.O. Sauer has called the aforesaid areas as the **'planting hearth'**. Four areas of the origin of cereal plants have been identified e.g. (i) **Guatemala-Mexico region**-where corn was domesticated for the first time and beans and squashes were domesticated and developed at later date and these were, later on, dispersed and distributed by man into North

America and South America; (ii) **N.W. India-Eastern Mediterranean region** represents the first domestication and cultivation of wheat, barely, rhye, oat etc. which were later on dispersed and distributed by man in other parts of the world; (iii) **North China region**-where millets and soybeans were developed as domesticated crops, and (iv) **Abyssian Highlands region** (eastern Africa)-where sorghums were domesticated. Man has widely disperesed and distributed cereal plants from these aforesaid four principal areas of their domestication in those areas where he has migrated either permanently or temporarily.

The pace of migration of man to different parts of the world during the past 4-5 hundred years has been greatly accelerated because of (i) exploration of new areas, (ii) development of fastest means of transporatation and therefore reduction in distances in terms of time, (iii) growth in international trade and commerce etc. All these have resulted in large-scale migration of human beings in the different parts of the world and this migration has caused widespread dispersal and distribution of plants and animals from their places of origin and domestication to other parts of the world. It may be pointed out that in the beginning the dispersal and distribution of plants and animals were limited because of the presence of physical (geographical) barriers (e.g. high mountains, seas and oceans, extensive deserts and ice covered areas etc.) but man now has conquerred these obstacles because of the development of aeroplanes and ships which can carry man within short time from one end of the globe to the other end. Previously plants and animals mainly cereal plants were confined to the limits of hemisphere or continents but now these limits have been removed and the dispersal and distribution of cereal plants have become world-wide for example, (i) the introduction of potato, tobacco and corn in Europe, (ii) introduction of rubber and cincona in south-east Asia from South America, (iii) introduction of wheat, oat, rhye, barley, flax, sugarcane, paddy, banana from Asia and sorghum from Africa in South America etc. are the testimony of man-induced dispersion and distribution of cultivated plants.

It may be pointed out that the dispersal and distribution of plants by man is carried out in two ways e.g. (i) **Intentional dispersion**-when man intentionally brings with him the seeds of desired plants or even plants to those areas where he migrates to settle down or a country officially imports the seeds developed in other countries, (ii) **Unintentional dispersion**-some seeds are unintentionally transported by man during his migration from one place to another place but he does not know that he is transporting seeds with him. Such type of unintentional transport of seeds by man may be possible in a variety of way e.g. the seeds may be attached to the packings, to the means of transport (vehicles, ships, aeroplanes, etc.) to the human bodies and his cloths etc. and may be carried to the desired destinations where a few of them may be able to germinate (if environmental conditions of new places are favourable at least to minimum.level) and develop while others may perish. There has been phenomenal increase in the number of plant and animal species due to colonization of New Zealand and Hawaiiland by men because the native flora and fauna before the migration of men to these areas were limited in number.

A few plants introduced in new areas by man through intentional transport and dispersion have now become problems for human society. For example, since the time of first introduction of prickly pear cactus as fodder for animals in Australia from South America it has so enormously multiplied due to rapid rate of increase of its pastures that it has adversely affected and damaged the natural source of animal fodder. Similarly, kudzu (a type of vine creepers) was introduced in the U.S.A. from Japan to check soil and gully erosion but its growth has been so phenomenal that it has covered many areas of the U.S.A. and now it has become very difficult to eradicate this problematic plant from the U.S.A. The growth of Ipomoea Cornea, brought in India from North America, has been so rapid and enormous that it has spread in almost all parts of the country. This plant has become so problematic that there is need of movement from the government side as well as from the public side to eradicate this problem plant otherwise it will cover many of the agricultural fields. The dispersal of animals by man from one part of the world to the other part also poses great danger to native vegetation. For example, European rabbits and red deers brought in New Zealand have done extensive damage to natural vegetation which has a chain effects on the local environment e.g. phenomenal increase in the population of rabbits and red deers has resulted in the loss of natural vegetation (due to mass grazing by these foreign animals) which has caused extensive soil and gully erosion resulting into tremendous loss of good fertile soils and decrease in agricultural production and in the number of native animals.

10.6 DISPERSAL OF FLOWERING PLANTS

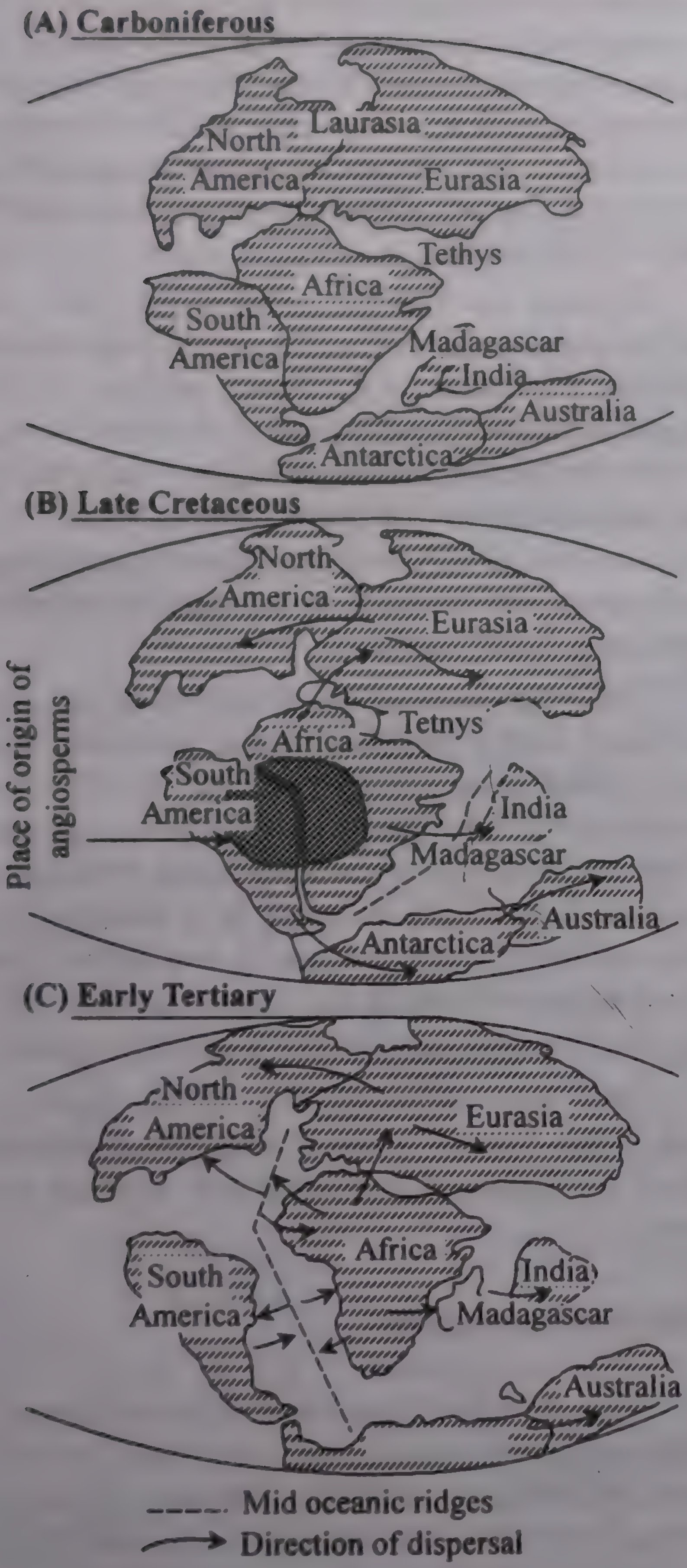
Figure 10.3 depicts the situations of the continents during (A) Carboniferous period, (B) late Cretaceous period, and (C) early Tertiary period wherein the directions of plant dispersal have been shown by arrows. There are contrasting opinions about the exact place of the origin of the flowering plants mainly the **angiosperms** during Cretaceous period. Some scientists are of the view that the flowering plants were originated in the areas of high latitudes mainly in the Arctic and Antarctic areas but D.I. Axelord (1961) has strongly refuted the aforesaid concept and has maintained that the flowering plants were originated in the tropical and subtropical areas. According to the recent views of D.I. Axelord and P.A. Raven (1974) the flowering plants are believed to have been originated in the western part of Gondwanaland (figure 10.3B) (during Cretaceous period) which now represents modern Africa and South America. Axelord and Raven have further maintained that there were different habitats having various combinations of the arid and semi-arid climatic conditions. The combinations of arid and semi-arid environmental conditions different types of soils and varying topographic characteristics provided favourable environmental conditions for the maximum and rapid rate of vegetative growth of the flowering plants in the tropical areas during Cretaceous period.

From this original nucleus (western part of Gondwanaland) of the origin of the flowering plants, the dispersal of plants was radiated in all directions, which continued from late Cretaceous to early Tertiary periods (fig. 10.3 B and C). The dispersal of plants from the said nucleus of origin was directed towards north into north Africa and Eurasia during late Cretaceous period. These flowering plants were redispersed from Europe westward into North America because North America was at that time (late Cretaceous and early Tertiary periods) united with Eurasia in the form of Laurasia. From the nucleus of South America the flowering plants were dispersed southward into South America and then eastward into Antarctica and Australia (fig. 10.3B). The flowering plants were also dispersed eastward from the African nucleus into India through Madagascar as these were united together. It is obvious that most of tropical and subtropical flowering plants were developed in India and Madagascar due to their dispersal from Africa during middle Cretaceous period. The dispersal of the flowering plants continued further eastward from Africa through Madagascar and India to South-East Asia.

The disruption of Gondwanaland began some 100 million years ago due to sea-floor spreading and the opening of South Atlantic ocean began with the westward drifting of South America. About 75-70 million years ago Indian subcontinent lost contact with Gondwanaland due to northward movement of Indian plate which resulted in the formation of Indian Ocean and widening of gap between Indian subcontinent and Australia. About 55-50 years ago (during middle Miocene period) Indian plate was subducted below Asiatic plate which resulted in the formation of the Himalayas. Due to this northward drift of the Indian subcontinent many plant and animal groups of the southern location were also drifted northward with the drifting of the Indian subcontinent to new locations but many groups of plants and animals of India having tropical origin and austral connections were lost during this northward movement of the landmass because the plant and animal groups had to move through different climatic zones. The formation of the Himalayas during Tertiary period presented a formidable geogrpahical barrier in the dispersal of plants and animals between India and Asia.

It has been already pointed out that the dispersal of plants and animals of tropical and subtropical origin to North America took place during Cretaceous and early Tertiary periods from western part of Gondwanaland (the nucleus of the flowering plants) via Africa and Europe when North America and Eurasia were united together as Laurasia. With the opening of the Atlantic ocean due to sea-floor spreading during early Tertiary period the water barrier prevented dispersal of plants and animals from Europe but still direct dispersal and migration of biota of cooler environmental conditions continued through the landmasses of higher latitudes because the landmasses of North America and Eurasia in the higher latitude were still connected together (fig. 10.3C). Some dispersal and migration also became possible through the volcanic islands associated with the mid-Atlantic ridge.

At present many groups of plants and animals such as nothofagus, southern beech, marsupials (such animals who carry their offsprings in the pouch attached to their stomachs, like kangaroo) are


(A) Carboniferous

(B) Late Cretaceous

(C) Early Tertiary

North America
Laurasia
Eurasia
Tethys
Africa
South America
Madagascar
India
Australia
Antarctica
North America
Eurasia
Tetnys
Africa
South America
India
Madagascar
Australia
Antarctica
Place of origin of angiosperms
North America
Eurasia
Africa
South America
India
Madagascar
Australia
----- Mid oceanic ridges
→ Direction of dispersal

Fig. 10.2 : Relationship between continental drift and plant dispersal. A-The position of continents during Carboniferous period, B-Position of continents during late Cretaceous period and the nucleus of the origin of the flowering plants (shown by oblique lines).
C-Position of continents during early Tertiary period and direction of plant dispersal.

found in the temperate areas of the southern continents, the member of previous Gondwanaland, e.g. South America and Australia including New Zealand.

It is believed that these plants and animals were first originated during early and middle Cretaceous period in the initial nucleus of South America and from there these were dispersed and migrated eastward into Australia and new Zealand before the disruption of Gondwanaland which began in late Cretaceous period but the separation of Australia from Antarctica and their drifting began during middle Miocene period some 55-50 years age. Due to northward movement of Australia, after breaking its connection with Gondwanaland, there was collision of Asiatic plate with Australian plate which provided a land connection between these two plates through New Guinea. This new land bridge between Australia and Asia provided new avenues for free exchange of biota of these two landmasses.

At the same time New Zealand broke away from Australia. Thus the isolation of Australia from the rest of Gondwanaland enabled it to possess its unique native plants (like eucalyptus) and animals (marsupials-kangaroo).

The evolution and development of vegetation of Antarctica right from the glossopteris of Permian period to the temperate flowering plants of mid-Tertiary period have taken place through many phases of successions of plant communities. The temperate flowering plants became extinct due to southward movement of Antarctica after middle Tertiary period because this movement ushered in cool climate which could not be tolerated by these plants. As the movement of Antarctica towards south pole continued, climate became more and more severe due to increasing cold and thickening of ice cover. This resulted into complete extinction of all plants. The earlier forests were replaced by tussock communities which were also eliminated at latter date due to the severity of climate. At present Antarctica is an ice covered sterile continent.

10.7 DISTRIBUTION OF PLANTS

There is a wide range of variations in the distribution of vegetation on the globe. There is a zonal pattern of vegetation from equator towards the poles and from sea level to vegetation level on the high mountains. The distribution of plants is affected and controlled by a variety of factors e.g. (i) **climatic factors** (sunlight, temperature, moisture and humidity, precipitation, soil-moisture etc.); (ii) **edaphic factors** (soil nutrients, soil texture, soil structure, aciditiy and alkalinity, nature and properties of soil profiles etc.); (iii) **biotic factors** (effects of living organisms mainly animals and man of particular habitat on plants, interactions between different plant species and between plants and animals like natural selection, competition, mutualism, pasasitism etc); (iv) **physical factors** (reliefs and topography, slope angle, gradient and slope aspect, etc.); (v) **tectonic factors** (continental displacement and drift, plate movements, endogenetic forces and movements, vulcanicity and seismic events etc.); (vi) **fire factor** (forest fire-natural forest fire through lightning, man-induced forest fire-both intentional and accidental; (vii) dispersion of plants, and (vii) human interferences.

Distribution of plants may be attempted in a variety of ways viz. (i) on the basis of habitats as the distribution of terrestrial and aquatic plants, (ii) on the basis of floral divisions, (iii) on the basis of latitudinal and altitudinal extents, (iv) on the basis of characteristic features of plant communities etc.

10.8 DISTRIBUTION OF TERRESTRIAL (LAND) PLANTS

The study of the distributional patterns of terrestrial plants may be attempted in two ways e.g. (i) World distribution of a particular plant species-which includes the consideration of the distributional patterns of plants and their diversity in relation to climatic variations, dispersion and migration of plants and continental displacement and drift. (ii) The study of vegetation distribution through ecosystems-which involves the study of vegetation in terms of ecosystems wherein all species of plants of different habitats having same environmental conditions are studied collectively. In geography the distribution of vegetation is studied in terms of geographical and climatic regions.

Different but definite groups and assemblages of plants occupying definite areas on the earth's surface have emerged due to continuous dispersion and migration of plants mainly flowering plants from their centres of origin (eastern South America and Western Africa) in different parts of the world since Cretaceous period. The largest form of group or assemblage of plants occupying definite habitats of almost uniform environmental conditions is called **floristic kingdom** whereas the smaller group covering smaller area is called **floristic province** or **region.** It may be pointed out that there are variations in plants at regional level even in floristic kingdoms and therefore each floristic kingdom is sub-divided into several floristic provinces or regions covering much smaller areas.

It may be further pointed out that each floristic province includes all types of plants having different life-forms e.g. trees, bushes, shrubs, grasses and lichens and mosses. It is obvious that a floristic or floral province or region represents the total vegetation of particular region. Thus floral region is also called formation. The total assemblage of all plants and animals of a given ecosystem or habitat is called biome.

The vegetation or floral regions of the world developed during Tertiary period but these floral regions have been greatly affected, modified and tranformed by the climatic changes which occurred during Quaternary period mainly during Plesistocene and post-Pleistocence periods. It is interesting to point out that only a few species of plants could attain the status of world distribution as many of the plant species were confined to a specific location.

The land plant species of the world are grouped into 6 major floristic kingdoms on the basis of their worldwide distribution (fig. 10.4) as given below :

(1) Australian Region

This floristic kingdom includes the plants of whole Australia which is characterized by typical plant species e.g. eucalyptus. The different species of this unique genera of encalyptus are so dominant in Australia that they represent 75 percent of all Australian plants. There are over 600 species of eucalyptus which greatly vary as regards their general characteristics as they range from tall, giant and shady ecucalyptus trees to dwarf and stunted desert ecucalyptus trees. Eucalyptus is said to be related to mimosa which is still found in South America (only a few species). Eucalyptus has been dispersed and distributed by man (deliberately) from Australia to almost every continent. One can see extensive plantation of eucalyptus in India particularly along the rail and road sides and it is being expanded rapidly by deliberate actions of man in all parts of the country irrespective of environmental requirements and suitability of this unique exotic plant. The typial endemic flora of Australia having unique characteristics have developed due to its isolation from other continents of the southern hemisphere because of continental drift.

(2) Cape Region

The floral kingdom has developed in the southern tip of Africa wherein the plants having bulbs and tubers have developed and these represent the typical plant species of this floral kingdom. The plants of this kingdom belong to the category of cryptophytes which bear their buds in the form of bulbs and tubers which are buried in the soils. These bulbs and tubers give birth to other plants as new shoots come out from these bulbs and tubers and are developed as plants. These plants represent most plants of the gardens such as garden flowering plants (e.g. loplia, kniphogia, erica freesia etc.). The dispersal of these garden plants became possible when South Africa was colonized by Europeans who distributed these garden flowering plants from South Africa to the gardens of other parts of the

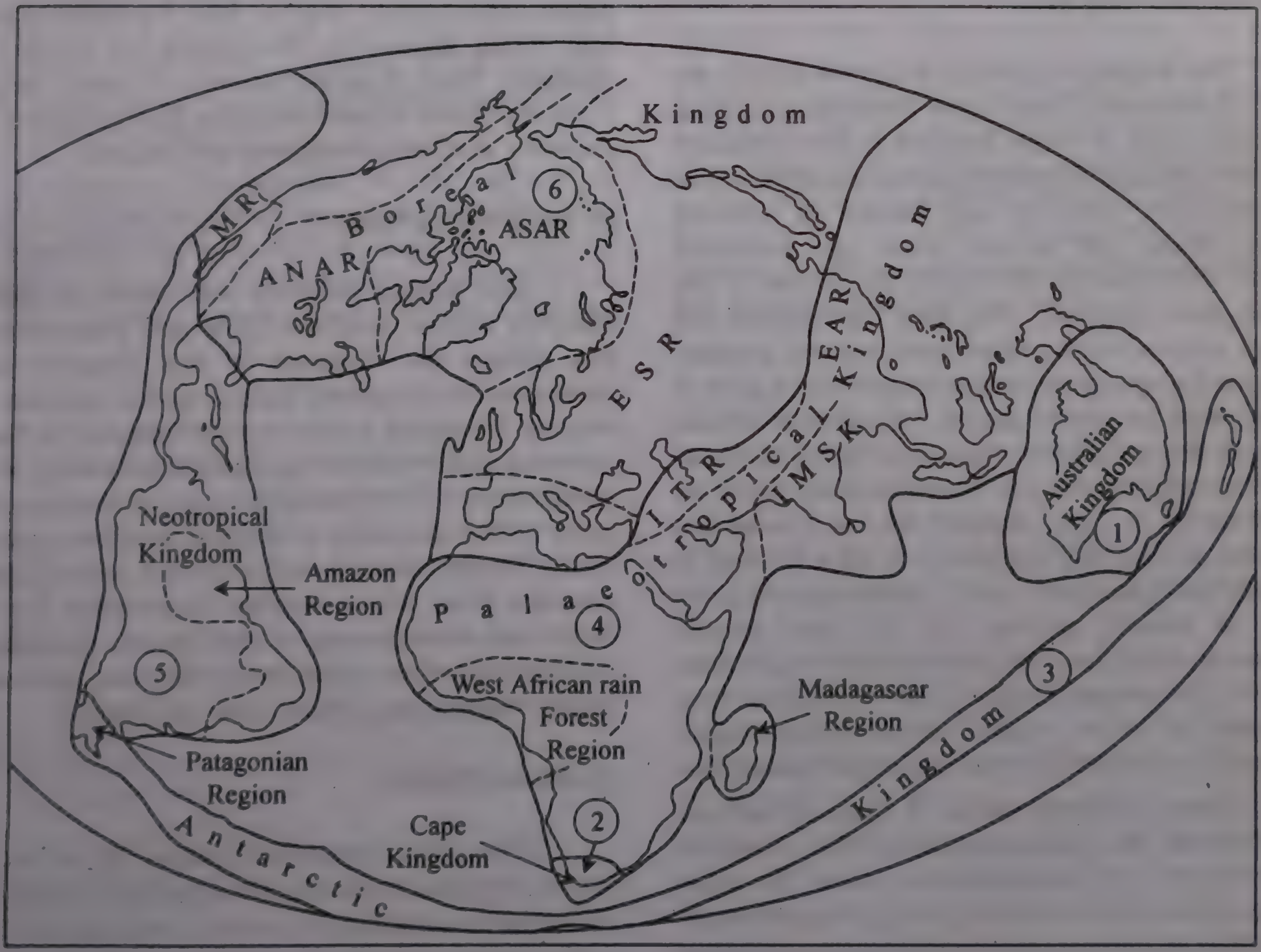

Kingdom
Boreal
6
ASAR
ANAR
MR
ESR
EAR
Kingdom
IMSK
ITR
Palaeotropical
Neotropical Kingdom
Amazon Region
5
Australian Kingdom
1
4
West African rain Forest Region
Madagascar Region
3
Kingdom
Patagonian Region
Antarctic
Cape Kingdom
2

Fig.10.3 : The present-day distribution of land plants. The major floral kingdoms and floral regions have been demarcated on the basis of dominant flowering trees and their species, IMSK-Indo-Malayan subkingdom; EAR-East Asian Region; ESR-Euro-Siberian Region; ITR-Iran-Turanian Region; MR-Mediterranean Region; ANAR-Atlantic-North American Region; ASAR-Arctic and Sub-Arctic Region. The solid lines denote boundaries of major floral kingdoms whereas dashed lines indicate the limits of floral regions.

world. There is gradual decrease in the number and area of these garden flowering plants in their own native areas (southern part of South Africa) because their areas are continuously being replaced by agricultural lands. The untouched areas still have sclerophyllous shrubs which attain the height of a few meters. There is undergrowth of herbaceous shrubs in the sclerophyllous shrubs. It may be remembered that the native vegetation of this region before the European colonization consisted of temperate evergreen forests which were extensively cleared off by the Europeans for agricultural purposes and thus the sclerophyllous shrubs developed in this region at later date as secondary succession of vegetation.

(3) Antarctic Region

This kingdom includes a narrow strip in the north of Antarctica which runs from Patagonia and southern Chile of South America to New Zealand. The most important representative plant of this zone is nothofagus which is also known as southern beech. About 100 million years ago temperate grasses developed as the native vegetation of this region (New Zealand). The most outstanding and typical species of the grasses were tussock grassses though a few species of sedges (plants which grow in water) and dicotyledon shurbs were also developed but these original native vegetations have undergone massive modification and transformation since the colonization of New Zealand by the Europeans. Thus the present-day vegetation of New Zealand is of modified type which is still characterized by two types of tussock grasses viz. (i) **short tussock grasslands**-which have two main species e.g. festuca and poa. The average height of these grasses is upto 0.5m and the colour is yellow-grey. (ii) **tall tussock grasslands**-which have the main species of chiomechloa.

Warm temperate areas of New Zeland are characterized by the dominance of the forests of gymnosperms and angiospherms trees. The main species of the coniferous family of gymnosperms are podcarpaceae, cupressaceae and araucariacae whereas flowring plants are included in angiosperms of which nothofagus is the most important plant.

The sub-tropical forests of New Zealand are of evergreen type which is characterized by dense cover of tall trees having different vertical strata of other plants. The original vegetation of New Zealand has been greatly modified and destroyed by human activities and the mammals (mainly grazing red deers and rabbits) brought by them from Europe. This has led to the destabilization of vegetation community at large scale.

(4) Palaeotropical Region

This kingdom includes most of Africa, South West Asia, South Asia, South East Asia and southern and middle portions of China. This floral kingdom is further divided into 3 sub-kingdoms e.g. (i) African sub-kingdom, (ii) Indo-Malaysian sub-kingdom, and (iii) Polynesian sub-kingdom. This floral kingdom is also divided into several floral provinces or regions (fig. 10.4) e.g. West African rainforest region, Madagascar region, Iran-Turanian region, East Asian region, etc. For details see chapter 12 (**biomes**). There is great variation in plant species from one region to another region but few plants are common to all sub-kingdoms and regions.

(5) Neotropical Region

This region includes the whole of South America except southern Chile and Patagonia. A few genera are common to this kingdom and palaeotropical kingdom mainly Africa because the original flowering plants were developed in South America and Africa during Cretaceous period when all members of Gondwanaland were united together. Later on the spreading of Atlantic seafloor, disruption of Gondwanaland and westward drift of South America from Africa became responsible for the origin and development of new species at regional level and therefore variations in the plant species of South America and Africa were introduced.

(6) Boreal Region

This floral kingdom includes the whole of North America except middle America, Greenland, entire Europe, northern Asia and Arctic region. This is the most extensive kingdom of all the floral kingdoms. This is again divided into several sub-kingdoms and regions or provinces e.g. Rocky Mountainous Region (RMR); Atlantic-North American Region (ANAR, fig. 10.4); Arctic and Sub-Arctic Region (ASAR); Europe-Siberian Region (ESR); Mediterranean Region (MR) etc.

See chapter 12 (biomes) for detailed discussion on species, genera and family of plants and major vegetation of the aforesaid floral kingdoms and floral provinces or regions.

10.8 DISTRIBUTION OF AQUATIC PLANTS

The habitats of plants are divided into two major types e.g. (i) land habitats, and (ii) aquatic or water habitats. Aquatic habitats are further divided into two sub-types e.g. (i) marine habitats, and (ii) fresh-water habitats which are further divided into two sub-types e.g. (a) mobile fresh water habitats (e.g. rivers), and (b) static freshwater habitats (e.g. lakes, tanks, reservoirs, ponds etc.).

Marine habitats are further divided into two sub-divisions e.g. (a) pelagic marine habitats (which include the entire water of the seas and the oceans), and (b) benthic habitats (which include only the sea beds and sea bottoms).

There are few number of plant species of marine habitats than the plant species of terrestrial or land habitats. The marine plant kingdom consists of mainly microscopic phytoplanktons and different types of algae living in the beds of shallow seas and oceans. There is more or less uniformity in the general characteristics of marine plants because there are no physical or geographical barriers like those in the terrestrial (land) habitats, rather there is free mixing among marine plants because of oceanic movements (e.g. sea waves, tidal currents, oceanic currents etc.) and there is no significant temperature variation in the marine habitats as is in the land habitats.

There is greater variation in the general characteristics between the marine plants living in the sea beds and floating on the upper water surface. Marine plants are divided into two major groups on the basis of marine thermal conditions e.g. (i) plants of warm oceanic water, and (ii) plants of cool oceanic water. Most of the genera and species of the marine plants are found in the warm water zones of the tropical areas which are divided into four zones e.g. (i) Atlantic-tropical zone; (ii) Indian Ocean-tropical zone; (iii) Western Pacific Ocean-tropical zone; and (iv) the Eastern Pacific Ocean-tropical Zone. Most of the plant types of the marine habitats are found in the continental shelves of Indian Ocean-Western Pacific Ocean region. See chapter 12 (**biomes-marine biome**) for the detailed description of the distribution of marine plants.

11

ANIMAL KINGDOM

The geographical study of animals is called **zoogeogrphy** which includes the consideration of classification, historical evolution and spatial distribution of different kinds of animals to be found in the biosphere. All these require the identification and determination of all animals of a particular region or habitat having certain environmental conditions, their classification on various bases and considerations, and their distributional patterns. The most important variations between plants and animals are related to their mobility and stability. Almost all the plants are static at their places except a few floating aquatic plants which move to some extent under the influence of water movements whereas animals (both land and aquatic animals) are very much mobile. Most of the plants are autotrophic phototrophs and primary producers while all animals are consumers (whether primay consumers like grazing herbivorous animals or secondary consumers like carnivorous and omnivorous animals mostly man). The following characteristics of animals differentiate them from plants.

- The metabolism of animals is not photosynthetic as is the case of plants. It means that animals do not prepare their own food rather they depend on plants for their food. Thus animals are consumers and heterotrophs whereas plants are producers and autotrophs. Animals also depend on herbivorous animals for their food. Thus animals derive their food from various sources viz. (1) from autotrophic plants (as herbivorous grazing animals like cows, goats, deers, etc.); (ii) from herbivours animals (carnivorous animals like lions, tigers, wolves, man etc.); (iii) from autotrophic plants (in the form of vegetables, food crops etc.) as well as from herbivorous animals (omnivorous animals like man); and (iv) from dead parts of plants and animals (detrivorous microscopic organisms or microbes or decomposers).
- Animals have maximum mobility but the degree of mobility ranges from one group of animals to the other group whereas plants are mostly static in their places.
- Every animal has a complete life-cycle wherein it attains its definite adult form in a definite time-span.
- There is absence of cell vacuoles (empty space in the cell) and rigid cell walls in the animals while most of the cellular and multicellular plants are characterized by these characteristic features.

- There is quick and rapid response among the animals to the external stimuli. In other words, the animals are very much sensitive to external stimulating events.

11.1 ORIGIN AND EVOLUTION OF ANIMALS

The only sources of the evidences of the origin of the oldest animals on the earth's surface are fossils preserved in the sedimentary rocks of different geological periods. These fossils provide only the rough estimates about the origin of animals because the fossils have also undergone large-scale modifications and transformations. It is estimated on the basis of fossils found in different rocks that the earliest invertebrate microscopic organisms might have evolved some 4600 millions years ago during late pre-Cambrian period in marine environment though very rare fossils of these primitive organisms are traceable. The following is the chronological sequence of the origin and evolution of animals through geological periods :

Pre-Cambrian Period

According to H. Clemmay (1976) the fossils of the oldest animals have been found in Zambia (Africa). These fossils indicate that the earliest animals might have evolved in the said area some 1000 million years ago. The primitive earliest animals belonged to the category of **detrivores** which derived their food from the detritus because no autotrophic plants could be evolved by that time. The fossils of softbodied invertebrate animals like jellyfish, segmented worms, and soft corals have been found from the Ediacara Hills of South Australia. These organisms were evolved in marine environment because these belonged to the groups of marine organisms which date back to 680-580 million years ago. The fossils of similar organisms have been found in modern Australia, Europe, Africa, and North America. It may be pointed out that these continents, which are now separated from each other, might have been united together during pre-Cambrian period so that the dispersal of animals to the locations of the aforesaid continents might have become possible.

Cambrian Period

From 600 to 500 million years ago the climate at global level during Cambrian period became wamer while it was cooler during pre-Cambrian period. Consequently, algae, fungi and bacteria as plants and several varieties of microscopic organisms and invertebrate animals (such as unicelular organisms of the Phylum protozoa, sponges, brachiopods, sea urchins, sea cucumbers, starfishes, molluscus etc.) were evolved in marine environments mainly inland seas. The animals of this period were dominated by 'trillobites' and 'brachiopods' (it is estimated that there were 1000 species of trillobites during Cambrian period).

Ordovician Period

Ordovician period (500 million years from present, total duration, 60 million years) was characterized by the first appearance of vertebrate animals in the freshwater environment. These vertebrates were characterized by jawless bodies but by bony armour around their bodies. These bony armours conferred on them protection from other organisms and from the severity of the environments. Snails, corals, sponges and squid-like animals developed in the oceanic environments.

Silurian Period

Silurian period (440 million years before present, total period, 40 million years) again saw a global climatic change wherein the climate changed from warmer type of the Ordovician period to cooler type. The geological and tectonic activities were dominated by large-scale mountain building. The primitive inland seas were dominated by marine algae whereas first land plant in the form of clubmoss was developed in the surroundings of the inland seas. Because of the richness of land and water flora a large variety of animals was evolved and there was wide expansion of already evolved invertebrates. This period saw the first appearance of land invertebrate animals. The carnivorous many-armed molluscs belonging to the group of nautiloids were the most dominant animals of this period. It may be pointed out that largest fossil shell of nautiloids measuring about 5m in length has been found so far. The other important organisms of this period included several types of snails, brachiopods, graptolites, corals, jellyfish, carnivous sea lillies, giant sea scorpions etc.

Devonian Period

Devonian period (before 400 million years from present, total duration, 50 million years) was characterized by maximum development in the life-form of primitive animals because there was broad distribution of uniform climates which were characterized by increased temperatures and aridity. The most outstanding advancement in the evolution took place in the primitive fishes as these first developed bony gills which were later on transformed into jaws. The freshwater fishes were endowed with additional characteristic features e.g. habit and capability of invading and attacking other organisms to catch their prey and ability to compete with other organisms to get food. The first amphibians and spiders were evolved during this period. There was wide expansion and dispersal of primitive fishes. The increasing aridity provided additional qualities to few organisms to withstand extreme hot and dry conditions. Many land animals developed burrowing habits and thus they used to live in the burrows in order to escape from prolonged droughts. The diversification in the floral system because of the development of first forests consisting of many trees mainly horsetails, ferns, liverworts etc. resulted into phenomenal increase in the numbers and species of animals because of the fact that abundant food was available to the increasing population of animals. Several varieties of insects (such as mites, millipeds, centipeds) and flies were originated during Devonian period. A few special types of fishes (e.g. lobe finned fish) and amphibians with tails were also evolved during this period.

Carboniferous Period

Carboniferous period (before 350 million years from present, total duration, 80 million years) saw a great climatic change at global level as the Gondwanaland was extensively glaciated due to the onset of very cool climatic conditions. It may be pointed out that there is difference of opinion about the time of glaciation of Gondwanaland as a few scientists are of the opinion that Gondwanaland was glaciated during Permian period but majority of the scientists believe in Carboniferous glaciation of Gondwanaland. The Carboniferous glaciation of Gondwanaland (including South America, Africa, India, Australia and Antarctica as all these were united together) brought in several drastic changes in the floral and faunal kingdoms. Before the glaciation of Gondwanaland during late Carboniferous period there were evolved several types of plants and animals. There was phenomental increase in the number of insects. There was further development in amphibians and a few of them were evolved in reptiles. A few insects were developed into large preydator insects like giant dragonflies and spiders. The climate of Gondwanaland changed into very cool climate during the Carboniferous period due to which major parts of Gondwanaland were extensively glaciated. This Great Ice Age of Carboniferous period resulted into widespread extinction of several animal species but the animals, which became successful in withstanding the severe climatic conditions and ultimately could survive, became very strong and powerful. Amphibians still remained dominant animals but reptiles also increased their numbers.

Permian Period

Permian period (before 270 million years, total duration, 45 million years) : The Gondwanaland was still covered with ice sheets during early Permian period. All the landmasses were still united together as Pangaea. This period was dominated by many events like formation of mountains (e.g. the Applachians), their erosion and resultant degradation and lowering, origin of deserts, advancement and retreat of ice sheets etc. which so greatly affected the plants and animals that many of them could not withstand the extreme environmental conditions and thus became extinct but the survivors introduced a wide range of variations in the plant and animal species. Amphibians still dominated the animal kingdom but some reptiles were so greatly modified that they developed the characteristics of primitive mammals. These acquired the properties of brisk walking, running and swimming.

Triassic Period

Triassic period (225 million years B.P., total duration 45 million years) : though Pangaea was broken into two big landmasses (Laurasia and Gondwanaland) which were separated by Tethys Sea but these two landmasses were still linked by a few land bridges. There was development of worldwide tropical and sub-tropical climates and several deserts and phenomenal increase in the number of invertebrate animals mainly arthropods (e.g. spiders, scorpions etc.) First aquatic reptiles were evolved. A few reptiles developed the characteristics of primative flight mechanisms. Such reptiles were later on developed into birds due to the process of gradual evolution (this happened during succeeding Jurassic period).

Jurassic Period

Jurassic period (180 million years B.P., total duration, 45 million years) was characterized by world-wide warm climates and beginning of the disruption of Pangaea and continental drift though at a very small scale. The humid climate led to the expansion of coniferous, cycads and fern forests. A few plants developed flower-like structure which introduced diversity in the life-forms of insects. This period was characterized by the abundance of first birds, spread of reptiles, appearance of primitive mammals, evolution of species of dianosaurs which could live in marine habitats (e.g. plesiosaurs), evolution of primitive birds from such reptiles which had the primitive flight mechanisms (e.g. pterosaurs), evolution of first lizards and crocodiles etc. The most characteristic feature of this period was that a few animals with a method bearing live offsprings were evolved.

Cretaceous Period

Cretaceous period (135 million years B.P., total duration, 65 million years) : There was final disruption of Gondwanaland. Inland seas and swamps were formed. There was evolution and development of flowering plants but decrease in coniferous forests. Among the animals reptiles were reduced in number but there was phenomenal increase in the number of dianosaurs. Infact Cretaceous period is considered to be a period of climax development of dianosaurs. The gradual evolution of mammals continued. There was maximum development, growth and expansion of insectivores. A few of them evolved into the first placental animals. Different species of bony fishes were evolved in freshwater and marine water habitats. Creeping piosonous animals with tails were evolved during this period.

Eocene Period

Eocene period (70 million years B.P., total duration, 30 million years) : Tertiary epoch (70 million years B.P., total duration, 69 million years) includes Eocene, Oligocene, Miocene and Pliocene periods. This epoch was characterized by the origin of the youngest and tallest Alpine folded mountains (e.g. Rockies, Andes, Alps, Himalayas etc.), large-scale displacement and drift of continents and sea-floor spreading and the attainment of the present position of the continents and ocean basins. It may be pointed out that the present position of the continents and ocean basins is not permanent because the evidences of palaeomagnetism and sea-floor spreading indicate that the continents and ocean basins are constantly changing their positions with respect to each other.

The Eocene period was characterized by the development of climatic zones in early Eocene; large-scale denudation of continental masses; modernization and extension of flowering plants (angiospherms); evolutionary explosion of mammals (rapid rate of increase in the number, species and ocupied areas of mammals) and hence dominance of mammals over other animals; maximum diversity in the placental animals mainly insectivores and herbivores; evolution of the oldest carnivorous mammals; evolution of hoofed animals, rabbits and rodents-like primates; evolution of even-toed herbivores (such as deer and cattle) and later on odd-toed animals (such as horse, rhinoceros and hippopotamus; evolution of primitive mammals in the seas (ancestors of whales and porpoises) or in the air (ancestors of modern bats) and the establishment of regional patterns of fauna like earliest elephants in Africa, tapirs in Asia, horses in North America, armadillos in South America etc.

Oligocene Period

Oligocene period (40 million years B.P., total duration, 15 million years) was also characterized by widespread warm climates but at few places mainly in the high mountainous areas climates began to become cool because of everincreasing heights of the Alpine mountains. This phase of relatively cool climate resulted into the retreat of tropical vegetation from the northern hemisphere. There was evolution of the South American animals like agouits and capybaras in complete isolation because there was no migration of animals through the Bering Strait because of cooler climate and geographical barrier between Asia and North America. The modern mammals were evolved during this period.

Miocene Period

Miocene period (25 million years B.P., total duration, 14 million years) was characterized by cooling of climate, development of grasslands, decrease in forests, phenomenal increase in the number and species of mammals, migration of elephant-like animals from Asia to North America through Bering Strait, migration of animals from North America to South America through Panama etc.

Pliocene Period

Pliocene period (11 million years B.P., total duration, 10 million years) : Polar and temperate climates developed on either side of the equator. This period was characterized by rise of herbaceous plants, increase and spread of grasslands, increase in mammals, diversification of large and fast-running herbivorous animals, appearance of Hominids and Pongids etc.

Quaternary Period

Quaternary period (from 1,000,000 years, B.P. to the present time) consisting of Pleistocene Period (1,000,000 years B.P., total duration 9,90,000 years) and Holocene period (from 10,000 years B.P. to present time) was characterized by widespread global climatic change as the major parts of North America and Eurasia were covered by continental glaciers. Four phases of successive advancement of ice sheets during Pleistocene Ice Age have been recognized e.g. Gunj, Mindel, Riss and Wurm in Europe and Nebraskan, Kansan, Illinois and Wisconsin in North America. These are called glacial periods. Between two glacial periods there were interglacial periods when there was retreat of ice sheets. Thus there were four glacial periods characterized by advancement of ice sheets and four interglacial periods characterized by withdrawal or retreat of ice sheets.

The onset of cold climate and Pleistocene glaciation affected and modified the plants and animals on a large-scale. The most characteristic feature of this period was that there were several phases of dispersal, distribution and redistribution of plants and animals in response to the changing environmental conditions (four glacial and four warm interglacial periods during Pleistocene Ice Age). There was further increase in herbaceous vegetation but decrease in trees and forests because of covering of ground surface by ice sheets. There were several cases of extinction of many large mammals. For example, before Quaternary epoch elephant and hippopotamus-like animals were present in North America but there were no bisons and wapiti but at present elephants and hippopotamus have become totally extinct whereas bisons and wapiti are found in large numbers. The extreme cool climatic conditions and four cold periods of advancement of ice sheets and four warm interglacial periods of the withdrawal (retreat) of ice sheets had the following effects on animals.

(i) A few large animals faced mass extinction like dinosaurs because they were slow-moving animals due to heavy weight of their bodies and large tails, and (ii) brisk-walking and fast-running animals could survive because they rapidly migrated from the areas of extreme environmental conditions (cold climate and glaciated regions) to relatively favourable areas. This resulted in widespread migration and dispersal of animals which thus became responsible for the origin and evolution of new species through the process of speciation. North America lost its several animals (e.g. cats, bears, racoons, horses, peccaries) because these migrated from their native place to South America to get rid off extreme cold conditions but many animals of South America became extinct becasue of invasion of the aforesaid animals from the north.

According to L. Milne and M. Milne (1972) some parts of the north-eastern Siberia and north-western Alaska were not affected by Pleistocene glaciation and the Bering Strait was covered with grasslands and forests which facilitated free migration of bears, moose, white-tailed deers, wapiti, biason, mountain sheep and mountain goat, musk oxen, saiga, mammoths and even man (at a much later date) from Asia to North America (via Bering Strait). Beavers and camels were migrated from North America to Eurasia. The landbridge of middle America facilitated free exchange of several animals between North and South Americas e.g. capybaras, porcupines, armadillos, glyptodonts, ground sloths etc. migrated from South America to North America whereas carnivorous racoons, cats, bears, horses, elephants, hippopotamus, tapirs, llamas etc. were dispersed from North America to South America.

Though the modern man was evolved about 10,000 years ago but the initial stage of the evolution of man began from the origin of Primate Prosimians in early Eocene period or Palaeocene period (fig. 11.1). True Prosimians and man-like animals (An-

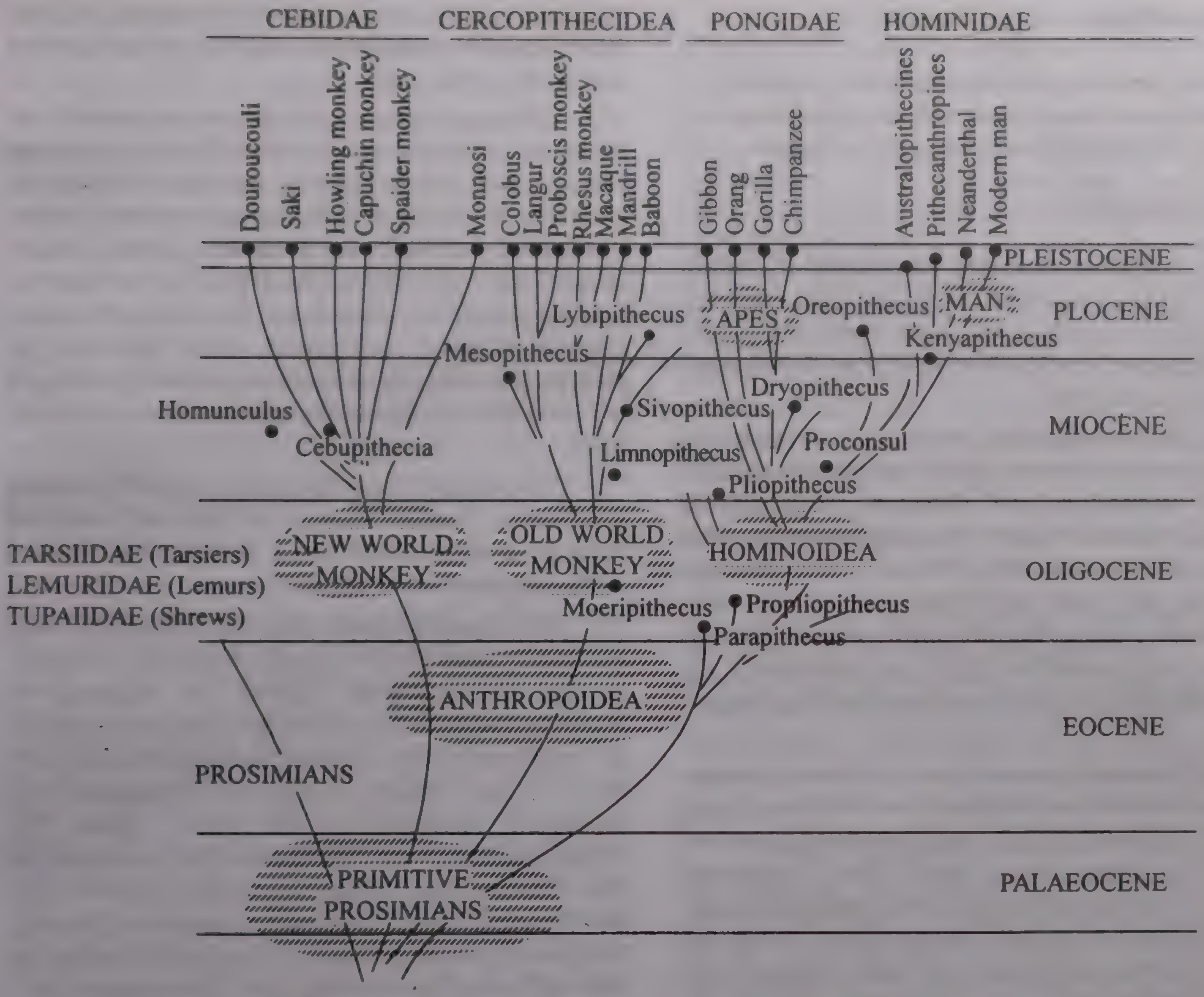

CEBIDAE
CERCOPITHECIDEA
PONGIDAE
HOMINIDAE
Dourouconli
Saki
Howling monkey
Capuchin monkey
Spaider monkey
Monnosi
Colobus
Langur
Proboscis monkey
Rhesus monkey
Macaque
Mandrill
Baboon
Gibbon
Orang
Gorilla
Chimpanzee
Australopithecines
Pithecanthropines
Neanderthal
Modern man
PLEISTOCENE
PLOCENE
MIOCENE
OLIGOCENE
EOCENE
PALAEOCENE
Lybipithecus
APES
Oreopithecus
MAN
Kenyapithecus
Mesopithecus
Dryopithecus
Sivopithecus
Homunculus
Cebupithecia
Limnopithecus
Proconsul
Pliopithecus
NEW WORLD MONKEY
OLD WORLD MONKEY
HOMINOIDEA
TARSIIDAE (Tarsiers)
LEMURIDAE (Lemurs)
TUPAIIDAE (Shrews)
Moeripithecus
Propliopithecus
Parapithecus
ANTHROPOIDEA
PROSIMIANS
PRIMITIVE PROSIMIANS

Fig. 11.1 : The evolution of Anthropoids (based on G.de Beer, 1964).

thropoidea) were evolved from Primate Prosimians during late Eocene period.

Shrews (tupaiidae, animals living on tree branches), tarsiers (tarsiidae, 'langur', still found in Africa), and lemurs, lemuridae still found in Madagascar) were evolved fom Prosimians during Oligocene period. Monkeys of New World (N. and S. Americas) like douroucouli, saki, howling monkey, capuchin moneky and spider monkey and monkeys of Old World e.g. colubus, langur, proboscis monkey, phesus monkey, macaque, mandrill and baboon were gradually evolved from anthropoidea (anthropods) of Eocene period whereas the third branch developed from primate of primitive prosimians was that of hominoidea which was evolved during Oligocene period. Further two branches were developed from Hominoidea during Miocene period e.g **apes** and **ape man** (early man). Gibbons, orangs, gorillas, and chimpanzee were evolved from apes during late Pleistocene period whereas the modern man was evolved from ape man.

Normally, the central-east Africa is considered as the original place of the origin of Homo Sapiens where the early man was evolved some 40,000 years ago. The Australian anthropologist Alan Thorne and a few others viz. John Sherwood, Edmund Gill, Josephine Flood etc. are of the views on the basis of the fossils of marine organisms discovered from Warranambool located along the coastal cliff of southern Australia that the Homo Sapiens were evolved some 60,000 to 85,000 years ago in eastern Australia (Northern India Patrika, June 22, 1986, p.4) but this concept has not been corroborated by majority of anthropologists and biologists.

11.2 DISPERSAL OF ANIMALS

The spreading of animals from the places of their origin to other areas is called **Animal dispersal** which is divided in the following five types :

Types of Dispersal

(1) **Gradual dispersal** is secular in nature because it involves longer period of time and very slow rate of migration but such dispersal covers larger areas and results in wide-spread distribution of animals over time.

(2) **Rapid dispersal** involves mass exodus of animals from one area to other area but the animals involved in such type of dispersal are unable to colonize in the areas where they are rapidly migrated or dispersed because either they are not allowed by man or by the local environmental conditions to settle down in new habitats. Such rapid dispersal involves certain animals only e.g. lemmings, locusts, butterflies, several varieties of moths, dragonflies etc.

(3) **Seasonal dispersal** involves those seasonal migratory animals which leave their habitats due to seasonal extreme weather conditions every year and migrate to those areas which have favourable seasonal weather conditions. These migratory animals again return to their native places when the season becomes favourable for them. Many arctic birds leave their places during winter season every year because of the severity of cold and come to subtropical and tropical areas and they again return back to their respective native places during next summer season. The migratory birds, inspite of dangers of atmospheric storms, droughts and of man himself, millions in numbers, undertake bi-annual journeys covering the whole of continetns and oceans.

Some of the Greenland wheatears birds fly directly from Greenland to Spain during winter season covering a distance of 3,200 km. Similarly, blackpoll warbler (a small bird like sparrow) flies directly from New England of the U.S.A. during winter season to Venezuela of South America. Arctic terns cover the longest distance among all the seasonal migratory birds as these cover the total distance of over 35,000 km each year. Some of the Siberian Arctic terns have been located during summer season in Australia (there is winter season in the northern hemisphere). Many Siberian birds visit India each year during winter season and they return back to their native places during summer season the same year.

(4) **Forced dispersal** occurs when animals are forced to leave their native places due to sudden and catastrophic events having adverse effects on animals e.g. prolonged droughts, recurrent floods, forest fires, volcanic eruptions etc. All such severe events cause scarcity of food leading to famines. Consequently, the animals of the affected locality migrate to other such areas where they can get plentiful food. Many animals migrated from Siberia because of severe forest fire which broke out there in 1915.

Some times many animals migrate from their native areas because they do not find sufficient and suitable breeding places due to phenomenal increase in the populations of animals.

(5) **Anthropogenic dispersal** : Recently man has largely been involved in the dispersal of animals through his deliberate efforts. The dispersal of aniamls to very distant places by man has introduced diversification in the regional fauna on the one hand, while it has caused several environmental and ecological problems on the other hand. For example, the arrival of European deers and rabbits in New Zealand has resulted into large scale destruction of native natural vegetation due to mass grazing. This has led to accelerated rate of soil erosion and thus the loss of agricultural land and fertile soils.

Besides, dispersal of animals is also caused due to continental drift and climatic changes. The following are the important factors which affect dispersal and migration of animals :

Factors of Animal Dispersal

The dispersal and migration of animals are primarily the result of multi-facet interactions between one group of animals and the other groups and between animals and the environmental conditions of the habitats. The factors which stimulate, affect and control the dispersal of animals are generally grouped in two categories e.g. (1) environmetnal or physical factors, and (2) biotic factors.

Environmental Factors

Environmental factors include land and water distribution, sediments, physical barriers, physical events,distance etc. Lands and waters are barriers for the dispersal and migration of aquatic and terrestrial or land animals respectively. Water bodies such as large lakes, inland seas, and oceans are effective barriers for the dispersal and migration of land animals because most of the land animals lack in swimming mechanism. Even those land animals which have the swimming mechanisms cannot cross over the wide expansion of seas and oceans because of large distances. Thus the water bodies completely deter the dispersal of non-swimming animals, slow down the rate of dispersal of land animals having swimming mechanisms over smaller water bodies like lakes, and large water bodies like seas and oceans completely make the dispersal of land animals (whether having swimming mechanisms or not) impossible.

If such animals (having swimming mechanisms) venture in the seas and oceans, they die soon after they become tired. There is a genetic tendency among the lemmings of Norway to move westward every year (lemmings have inherited the habit of seasonal westward migration from their ancestors who used to migrate westward as North America was united with Eurasia before Jurassic period) and in doing so they die in the Atlantic Ocean (Norwegian Sea) every year. Several cases of water barriers have been reported e.g. (i) H. Wolda (1963) has reported from his studies of 'natural populations of polymorphic land snails' that about half of the total population of 300 snails of the species of Capaea nemoralis died while crossing a narrow ditch full of water (2.4 km wide); (ii) K. Zimmerman (1935) has reported through his study of 'race analysis of the middle European vole' that river Elbe is an effective barrier to voles because they cannot cross over the rivers; (iii) K.R. Kelson (1951) has reported that the families of rodents living on either side of the Colorado river do not have any contact and therefore they are also not related to each other.

The **properties of oceanic water** like salinity, density, temperature etc. also affect animal dispersal. For example, the animals of fresh water habitats (and having swimming mechanisms) cannot swim across saline sea water. If water bodies hinder, deter and taboo the dispersal of land animals, these also facilitate the dispesal, migration and spreading of aquatic animals but most of the aquatic animals cannot cross over the land surface because they do not have walking mechanisms.

Topographic factors such as high mountains, highly rugged and ravinated terrains, long, wide and deep valleys, extensive swamps and marshes, deserts whether warm or cold are effective barriers in the dispersal, migration and spreading of animals from their native places to other areas. There is wide range of variation between the animals of the northern and the southern sides of the Himalayas and the eastern and the western sides of the Rockies and the Andes because these lofty Alpine mountains are effective barriers which stop free exchange of animals of either side of these mountains but the natural passes or man-made passes (constructed for the highways) enable the animals of one side of a mountain barrier to migrate into the other side provided that there is no large-scale climatic difference between two sides of the mountain concerned.

Dispersal and migration of animals are also motivated by the typical characteristics of vegetation of a particular habitat. For example, a few insects such as western tent caterpillar lay their eggs on tall trees. The animals of such habits do not migrate to those areas where tall trees are not present.

Adverse and severe climates are also hurdles in the dispersal and migration of animals except seasonal migration. **Distance factor** is also important in the dispersal and migration of animals. If topographic and climatic uniformity is found over larger areas, gradual dispersal takes place without hindrance for longer distances but if the region is characterized by topographic and climatic heterogeneity or if there are frequent changes in topograhic characteristics and climatic conditions after short distances, dispersal is limited to only short distances. It is obvious that distance factor does not play an independent role rather it influences animal dispersal together with topographic and climatic factors.

Inhospitable environments also deter if not stop the dispersal and migration of animals. Such inhospitable habitats and environments are the plantless areas of soft deposits such as sands over vast areas in the form of deserts, toxic deposits derived from the recent volcanic eruptions and lava flows, vast cold deserts having permanent continental glaciers and ice sheets because such habitats do not have the necessary conditions to become suitable habitats as these lack in all of the basic requirements of animals e.g. favourable climatic conditions, availability of food, suitable places to live, to breed and to have sexual contacts.

It may be pointed out that under exceptional circumstances the animals tide over the barriers of inhospitable environments and become adapted to them while migrating through them. It may be remembered that the topographic and climatic barriers are not permanent, rather they change over geological time. The topographic characteristics are controlled by endogenetic movements and high mountains are continuously eroded and denuded and therefore are lowered down in height under prolonged period of crustal stability and thus topographic barriers of same geologcial period are eliminated but new barriers are created due to fresh orogeny. Similarly, previous oceans are removed due to collision of convergent plates whereas new seas and oceans are created due to divergent plates. The geological and geophysical evidences have proved that the Atlantic ocean has been closed and opened twice during the past geological time-scale. Simiarly, the climate of a given habitat changes over time. All these mean that no part of the globe is permanent barrier in the dispersal and migration of animals. Since the dimension and location of toporgraphic and climatic barriers change through time, animal dispersal and migration become possible over larger areas and thus the distributional pattern of animals becomes highly diversified.

(2) Biological Factors

Animals have certain intrinsic characteristics which motivate and stimulate them to change their places. Such intrinsic characteristics of animals is called **innate ability** which is also called **vagility** (the ability to move about and thus to succeed in the struggle for existence). The innate ability of animals includes those intrinsic properties of animals which enable them to move and migrate. Such intrinsic properties of animals include the ability and habit of burrowing, creeping and crawling, hopping, climbing, digging, running, leaping, swimming, flying etc. These qualities of animals not only determine the type of dispersal and migration but also determine the nature and rate of dispersal. When the animals become mobile and move out from their places motivated and stimulated by their intrinsic properties, the resultant dispersal is called **active dispersal** which is exclusively dependent on the degree of mobility of the animals. Besides, several inherited qualities and social behaviour also help in the active dispersal of animals. Some times the animal dispersal is effected by external carriers. Such dispersal is caleld **passive dispersal.**

Passive Dispersal

Passive dispersal of animals occurs when they are transported by other animals including man or by means of various types of transport developed by man (e.g. two wheelers like bicylces, scooters and motor cycles; four wheelers like cars and jeeps, buses and trucks; rails; ships and aeroplanes) or by natural means of transport such as rafts, ocean currents, winds etc.

Carriers of Dispersals

The carriers which help in the dispersal of animals (passive dispersals) are divided into four grops as follows :

(1) aeolian carriers,

(2) aquatic carriers,

(3) organismic carriers, and

(4) anthropogenous carriers.

(1) **Aeolian carriers** include airmasses and air currents which transport micro-organisms from one place to another place without the willingness of the organisms because gusty winds lift them and carry them to various destinations. The dispersal of micro-organisms by wind is called **animochore dispersal.** Several studies have been carried out about the dispersal of insects by wind e.g. (i) P.I. Darlington (1957) has reported that the force and insect-carrying power of winds increases approximately with the square of the velocity of wind; (ii) According to S.C. Kendeigh (1961) about 12.5 million insects are carried away per hour during summer season in the southern England etc. Some animals carried by wind aloft are attached to the aircrafts because of their (of such animals) inbuilt trapping devices and are carried away to far off places. This type of **trapped dispersal** takes place in diptera, hymenoptera, homoptera and other arthropod insects such as spiders and mites (are the animals which have wings of uniform structure-cicads).

Some animals have the ability and their natural habit to hop in the air for wind-assisted gliding. Such animals include caterpillars, squairels, lemurs, marsupials, lizards, frogs, snakes etc. These animals are picked up by atmospheric storms while they are in the air during hopping and glidding and thus are carried away over various sorts of physical barriers. Such aeolian dispersal is called **chance dispersal**. Hurricanes, typhoons, tornadoes and temperate cyclones are effective carriers of animals which have gliding habits.

(2) **Aquatic carriers** are mainly the sea waves, tidal currents and oceanic currents which carry smaller as well as larger animals (whether they have swimming mechanisms or not) to distant places. It may be pointed out that many of the animals become dead in transit. Such dispersal of animals is called as **hydrochore dispersal.** According to C.H. Lindroth (1957) the spread of staphylinid beetle in the north-western Europe, Spitzbergen, Iceland and Greenland has been possible through several branches of the Gulf Stream. Ocean currents have carried several types of animals to many isolated islands. It may be pointed out that long-distance transport of animals through oceanic water by ocean currents depends on a variety of intrinsic properties of the animals e.g. ability to withstand longer duration of immersion in the oceanic water, the characteristics of body surface of the animals in terms of the ability of water permeability, respiration ability, temperature and salinity of the oceanic water etc. Some aquatic animals are also transported by floating rafts and debris.

(3) **Organismic carriers** are those animals which are symbiotic in character. In other words, the animals which depend on each other and live together are called symbiotic animals. The dispersal caused by such animals is called **biochore dispersal.** Mostly parasites are dispersed by active and mobile animals. The biochore dispesal by animal is caused in two ways e.g. (i) **Ectozoic biochore dispersal** involves external transport of animals by carrier animals. This so happens when small animals are attached and stuck to the bodies of the carrier animals and thus these are transported and carried to various destinations which are visited by the carrier animals. Birds also help in ectozoic dispersal because these carry the eggs of other animals. Some times birds also carry insects, worms, snails etc. inadvertently. Wading animals like ducks, rails and terns transport smaller aquatic organisms to other places. When dolphins move in groups, enormous sea waves are generated. These dolphin generated sea waves cause mass movement of fish shoals in the direction of wave propagation. (ii) **Endozoic biochore dispersal** involves internal transport of parasitic organisms such as viruses. Such organisms are hidden in the stomach or are mixed with bloods, sputum and stool of animals and these organisms are carried away by the animals to various destinations. Several types of worms such as tape worms, ring worms etc. live in the stomachs of human beings as parasites and are carried away to far off places in the case of journeys to distant overseas countries undertaken by man.

(4) **Anthropogenous carriers** are the most powerful and effective means of passive dispersal and migration of animals involving the whole globe. The dispersal caused and effected by man is called **anthropochore dispersal,** which is of two types e.g. (i) deliberate dispersal, and (ii) accidental or inadvertent dispersal. The deliberate transport of birds, rabbits and deers from Europe to New Zealand and the transprot of several birds from Europe to North America are the examples of deliberate anthropochore dispersal. Accidental transport of animals involves the carriage of animals attached with human bodies, his luggages and means of transport. For example, brown rats are now widely distributed throughout the world because of their undesired transport to various parts of the world through ships. The deliberate transport of animals by man from their native places to other destinations has in some cases changed the natural distributional pattern of the concerned animals. For example, transport of lions from Africa to Great Britain has resulted into phenomenal increase in their numbers to such an extent that the density of lions per hectare of national parks in Great Britain has become much higher than their density in their native places in Africa.

The favourable environmental conditions of the regions where animals are transported by man whether by deliberate action or by accident, incourage rapid growth of populations of the transported animals and thus the spreading of concerned animals is accelerated. For example, one pair of European rabbits transported to Australia is capable of producing 90,00,000 offsprings within a period of only three years. European starling was brought to North America in 1989 and since then starlings have spread over larger area of the U.S.A. and Canada. The dispersal of African snails (fig. 11.2) to various parts of the world is the example of effective anthropogenic dispersal of animals.

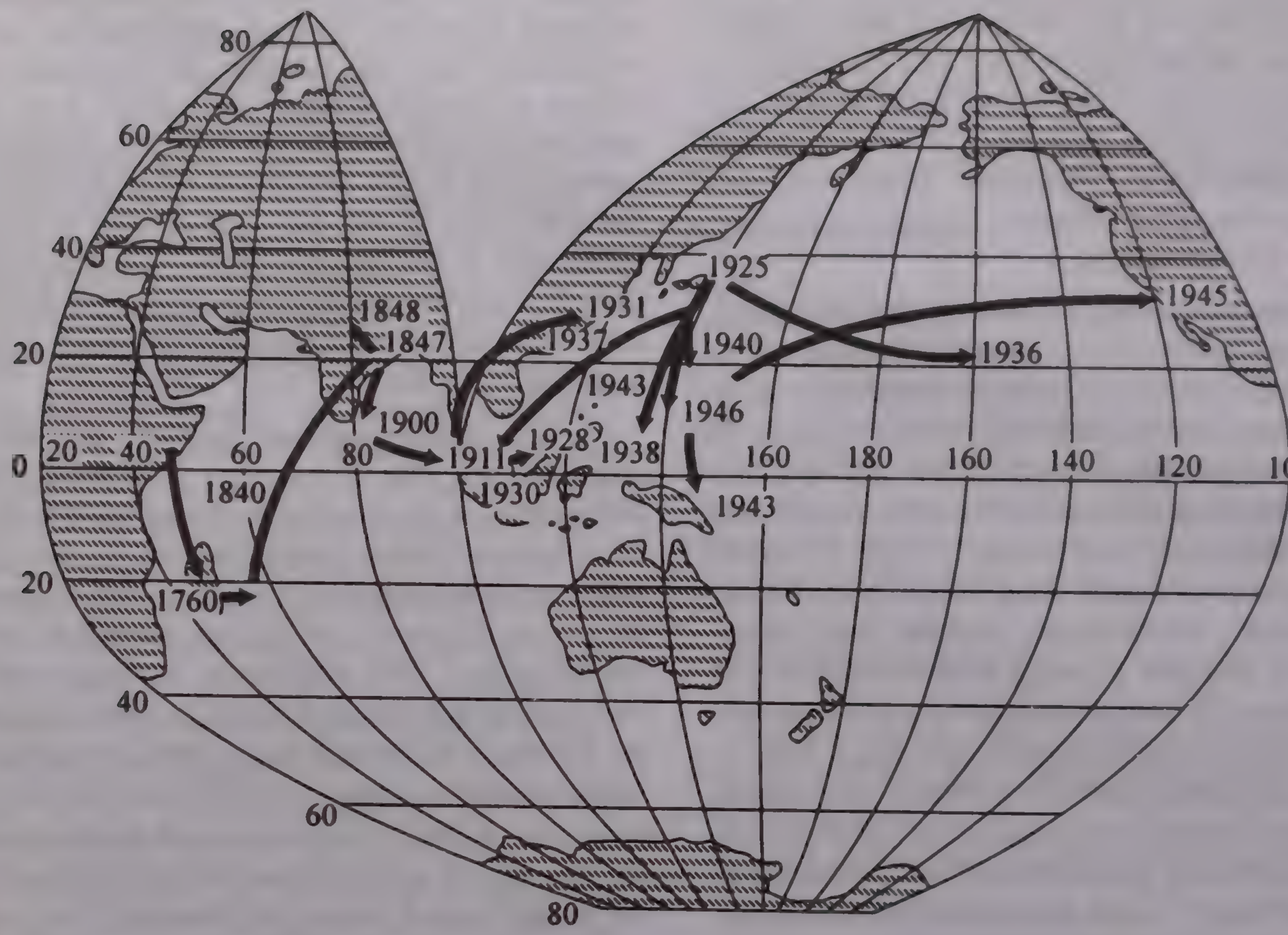


Fig. 11.2 : Dispersal of giant African snails by man between 1760 and 1945 (based on F. Okland, 1955).

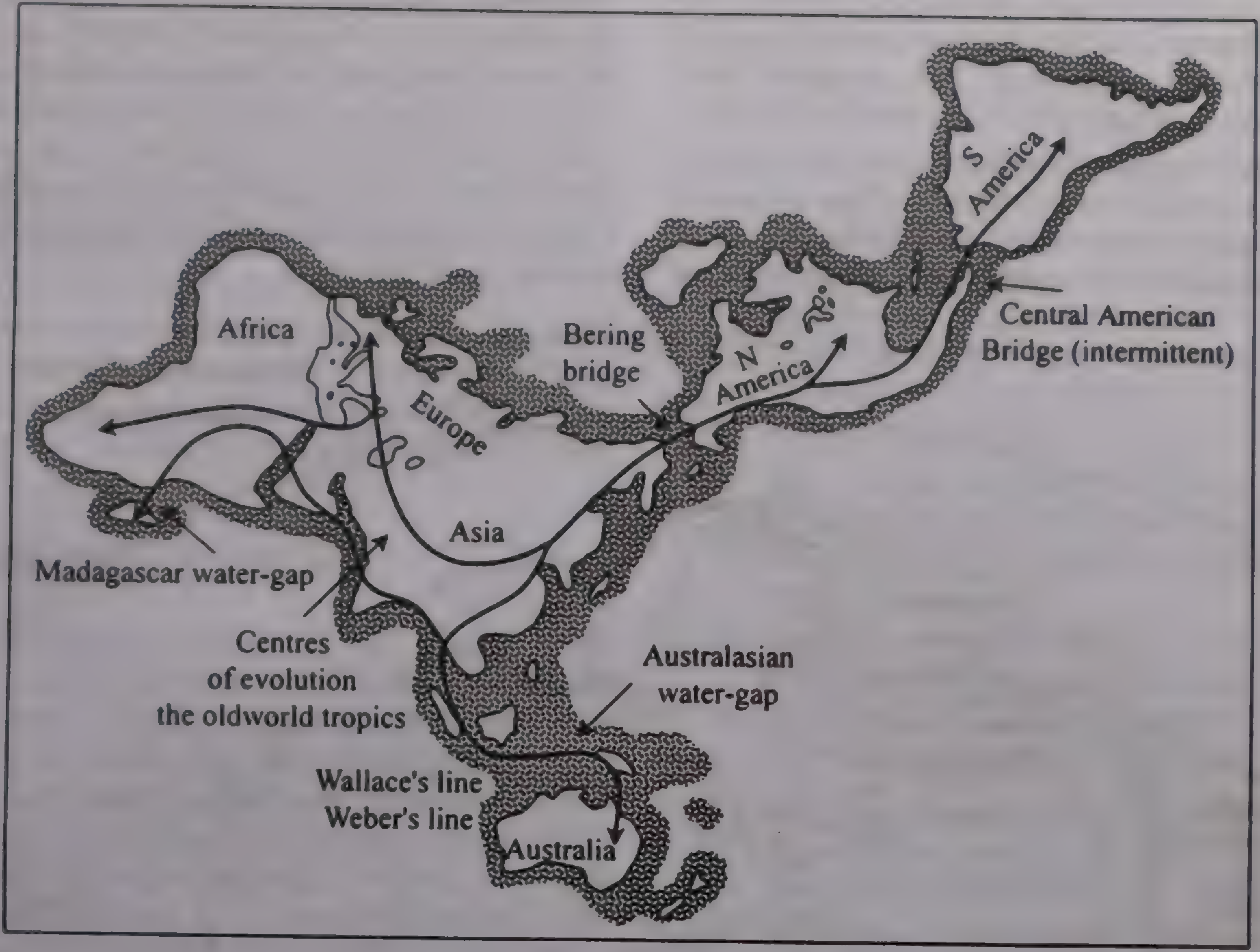
Active Dispersal

Active dispersal of animals takes place because of motivation of their intrinsic properties such as the properties of digging, burrowing, creeping and walking, hopping and running, floating, flying, climbing etc. These innate (inborn or inherent) abilities of animals motivate them to become mobile and move out of their places.

Natural dispersal of animals is a slow and gradual process which covers major part of the world. Fig. 11.3 depicts the nature and directions of natural dispersal of freshwater fish and land invertebrate animals since Mesozoic Era. The freshwater fishes and land invertebrates were originated in the tropical areas of the old world from where they migrated to Europe, Africa and Siberia (Asia). These animals crossed through Bering Strait to reach North America from where they spread in Canada and the U.S.A. ad migrated further southward through central American bridge (fig. 11.3) to South America. The migration of these animals from Asia to Australia was not smooth because of the presence of water gap (11.3).

Fig. 11.4 depicts the centres of evolution and dispersal routes of some ancient animals between Permian and late Triassic periods. Mesosaurs (a Permian reptile), glossopteris (Permian plant) and cynognathus (a reptile of late Triassic period) were originated in South America from where cynognathus and mesosaurs migrated to Africa and glossopteris plants migrated to Africa, Antrarctica, India and Australia. Lystrosaurs (late Triassic reptile) was originated in Africa from where it was dispersed to India and Australia.

Fig. 11.5 depicts major routes of widespread dispersal of plants and animals at global scale. Deer, saiga, sheep, bison, musk oxen, mastodons, mammoths, and man migrated from Asia to North America via Bering Bridge whereas beavers, opossums, raccoons, horses etc. migrated from North America to Asia via Bering Bridge. Raccoons, cats, horses, tapirs, Ilamas, camels etc. migrated from North America to South America via Central American Bridge whereas capybaras, porcupines, armadillos, glyptodonts, ground sloths, etc. were dispersed from South America to North America via


S America
Africa
Bering bridge
Central American Bridge (intermittent)
Europe
N America
Asia
Madagascar water-gap
Centres of evolution the oldworld tropics
Australasian water-gap
Wallace's line
Weber's line
Australia

Dig. 11.3 : Centres of evolution and dispersal routes of freshwater fishes and land invertebrate animals since Mesozoic era (based on G. de Beer, 1964).

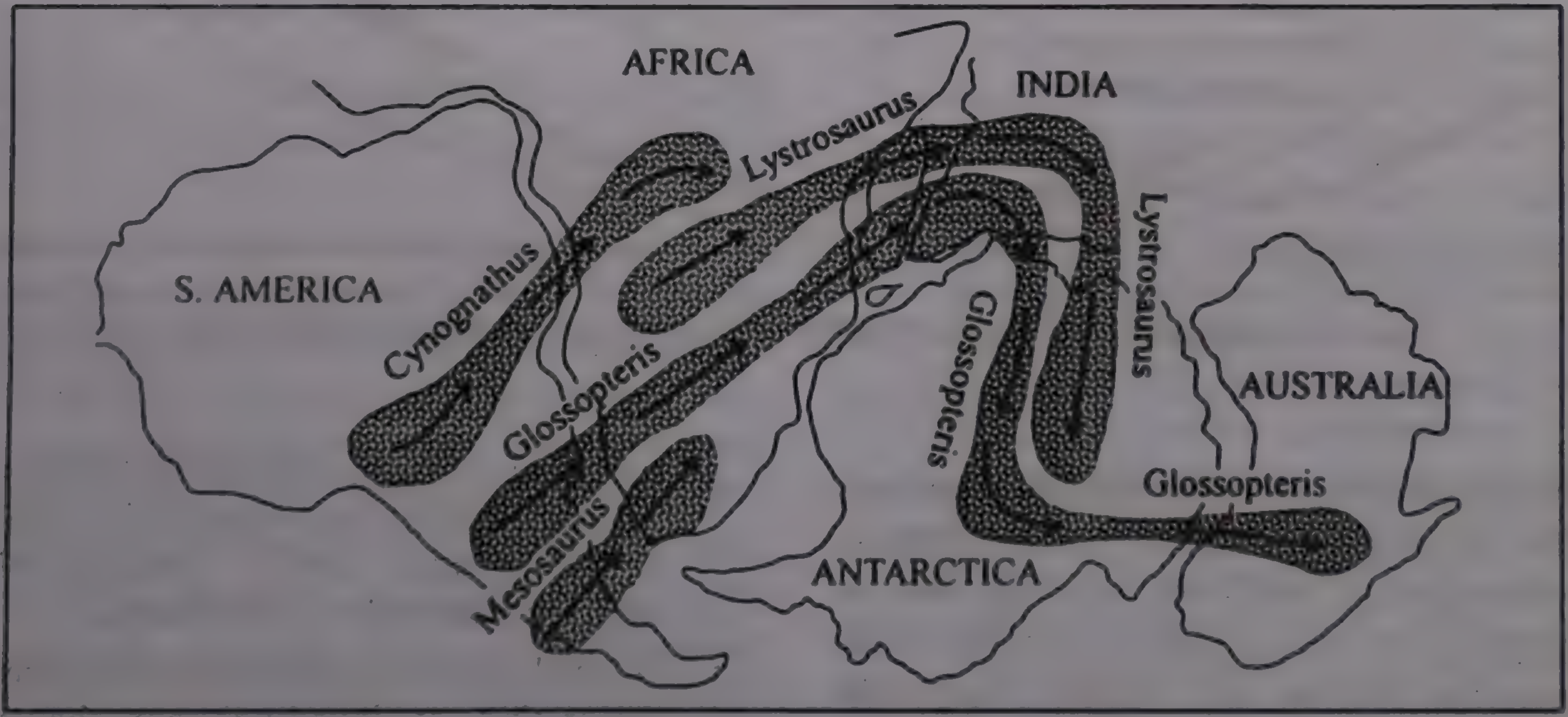

AFRICA
INDIA
Lystrosaurus
S. AMERICA
Cynognathus
Lystrosaurus
Glossopteris
Glossopteris
AUSTRALIA
Glossopteris
Mesosaurus
ANTARCTICA

Fig. 11.4 : Centres of origin and dispersal routes of mesosaurs, glossopteris (plant), lystrosaurs and cynognathus (after

Central American Bridge. Butterflies, moths, beetles, grosshoppers, lucusts, bugs etc. were dispersed from Africa to Europe and Asia whereas these animals were transported to South America by ships.

It may be pointed out that the fate of dispersal of animals is not always positive. The dispersal becomes unsuccessful when the animals dispersed to new habitats are unable to adapt to new environmental conditions and ultimately perish. On the other hand, the successful spread of animals becomes possible when dispersed animals become able to adapt to new environmental conditions and establish themselves in new habitats and start fresh colonization. There may be many alternative possibilities of dispersed animals from old habitat to new habitats as follows :

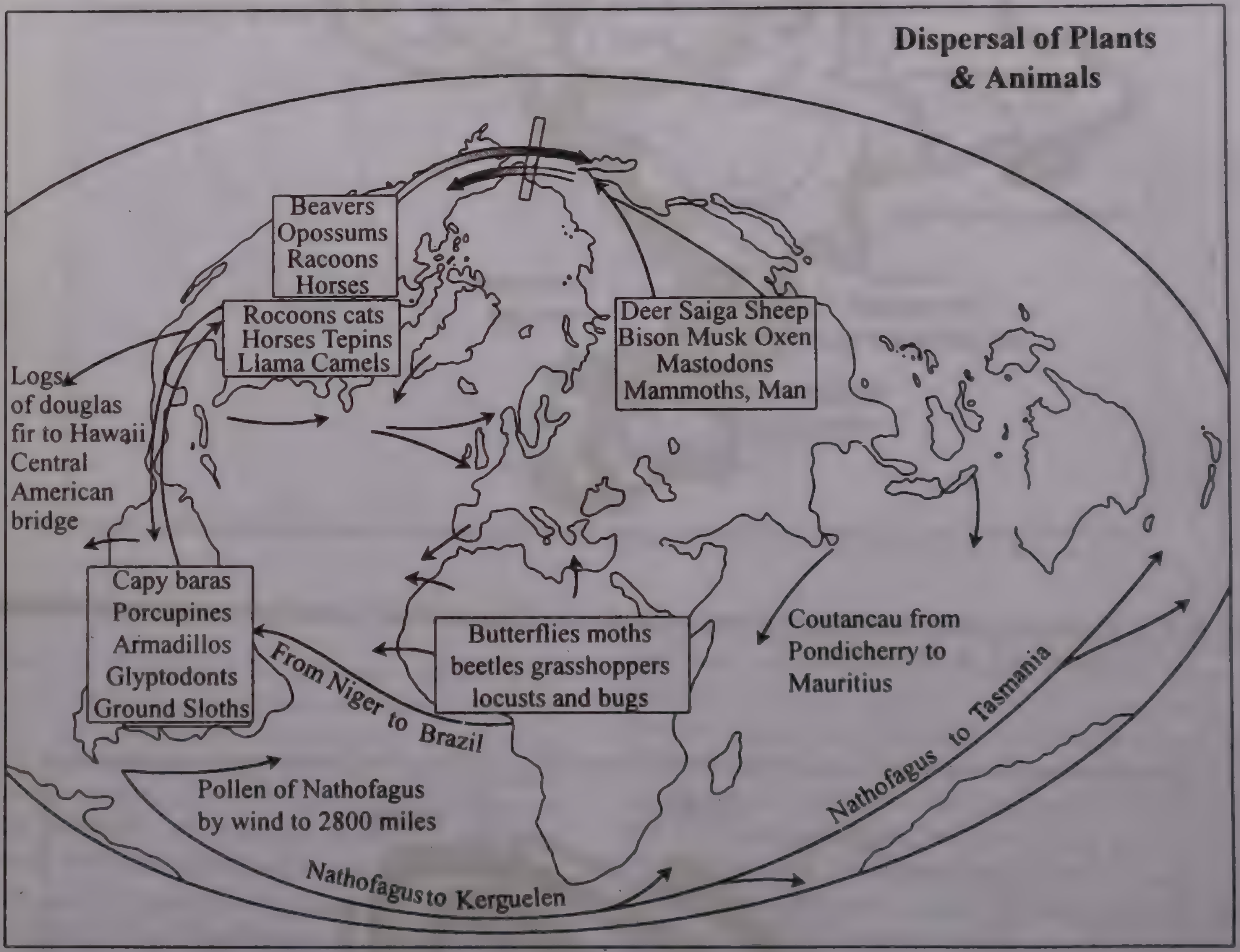

Dispersal of Plants & Animals
Beavers Opossums Racoons Horses
Rocoons cats Horses Tepins Llama Camels
Deer Saiga Sheep Bison Musk Oxen Mastodons Mammoths, Man
Logs of douglas fir to Hawaii
Central American bridge
Capy baras Porcupines Armadillos Glyptodonts Ground Sloths
From Niger to Brazil
Butterflies moths beetles grasshoppers locusts and bugs
Coutancau from Pondicherry to Mauritius
Nathofagus to Tasmania
Pollen of Nathofagus by wind to 2800 miles
Nathofagus to Kerguelen

Fig. 11.5 : Dispersal of animals and plants (both ancient and modern) at global scale.

- The migrating or invading species of animals after reaching new habitats having different environmental conditions may be able to compete with the original occupants of the concerned habitat and finally occupy the habitat.
- The migrating or invading species of animals may not be able to compete with the original occupants of the invaded habitat or may not be able to adapt to new environmental conditions of the invaded habitat. Consequently, the migrating animals are eliminated.
- It may be possible that neither the immigrants (migrating or invading) nor the original occupants of the concerned habitat are eliminated completely, rather both live in the same habitat.

- The migrating or invading animals may live in the open and vacant spaces of the new habitat and thus may form their own colonies through the process of gradual colonization.
- A few of the species of migrating or invading animals may establish sexual contacts with the original occupants and thus can produce hybrid species through interbreeding.
- If the environmental conditions of the habitat to which the animals have been migrated or dispersed are favourable, the migrating newcomers (animals) start colonization of the new habitat.

11.3 EXTINCTION OF SPECIES

Speciation (evolution of new species) and species extinction (complete elimination of species) are the natural processes which follow the evolution of animals. It is believed that about 200 species of mammals and birds have become extinct for the last 2000 years. Though there are several natural causes of species extinction but the modern man has accelerated the pace of animals extinction. The number of a few species of animals has come down to such a small size that if they are not provided immediate protection, they will soon become extinct. For example, the total population of 150 species of birds is believed to be only 2000 at present time, short - tailed albatrosses are only 100 in number and about 100 mammals are facing immediate extinction.

Extinction of animals may take place in a number of ways due to a variety of causes as given below :

- **Sudden and rapid changes of environmental conditions** cause species extinction. It is an established ecological principle that the environmental conditions of any region may change. The change may be gradual and long-term or it may be sudden and short-term. If the environmental conditions of any region change gradually, the animals of that region also try to adjust and adapt to new environmental conditions and sometimes they become successful to survive. But if the environmental conditions change so rapidly that the animals are unable to adapt to new changed environmental conditions, several species become extint. In other words, if the rate of environmental change exceeds the rate of adaptation by animals to changed environmental conditions, many species become extinct. The mass extinction of dinosaurs is believed to have been effected because of sudden drop in temperature during the early period of Tertiary Epoch. The dinosaurs having a large body and unproportionately long tail could not move to other places to escape from the excessive cold and therefore they perished and became extinct.
- The sudden **outbreak of disease and pest infections** caused by changed environmental conditions of the region concerned causes species extinctions.
- Some **sudden events** like forest fires, volcanic eruption etc. cause species extinction. Violent explosion of Kratatao in 1883 led to mass extinction of species of that island.
- **Direct hunting** and persecution of species lead to **'selective mass extinction.** P.S. Martin (1967) has suggested three alternative hypotheses of 'selective mass extinction'.

(a) **Ecological substitution** by other species of large carnivorous animals which compete for the same food resources.

(b) **Climatic change** accelerates the competition between large mammals for shelter and food.

(c) **over-killing** of certain species by man.

- Some weaker species become extinct as these perish during the course of competition with most powerful and strongest species.
- Man-induced environmental changes also cause species extinctions. Man changes the environmental conditions both intentionally and unintentionally through a variety of his activities e.g. habitat removal, land use changes, weather modifications, chemical and atomic wars etc. Human activities also alter the equilibrium state of ecosystem which causes extinction of some species at local scale or regional scale. Man's continued interference with natural environment at local and regional levels has led to destabilization of environmental and ecological eqilibrium and several species of animals are facing **threatened extinctions.** According to R. Silverberg (1973) only two kinds of mammals became

extinct at world level during 1801-1850; the period 1851-1900 registered upward trend in the species extinction as 31 kinds of mammals became extinct; there were extinctions of 41 kinds of animals in the next period from 1901 to 1944. It may be pointed out that extinction is an inherent natural ecological process and there is natural balance or dynamic equilibrium between speciation, dispersal and extinction but man-induced extinction may upset this balance which may cause hazardous and disastrous ecological problems to human society.

11.4 WORLD DISTRIBUTION OF ANIMALS

The study of distributional patterns of animals at global scale is carried out in different ways e.g. (i) collective study of the distributional patterns of all members of particular species. This involves the division of animals in definite distributional areas on the basis of the abundance of animals species; (ii) Animal distribution is also studied at community level which involves the consideration and study of total population of all individuals of all species of a given region. It may be pointed out that the distributional patterns of animals at global or regional levels are more complex than the distribution of vegetation because animals are very much mobile. Thus no animal species is universally distributed because several factors distort the uniformity of distributional patterns of animals.

Controlling Factors of Animal Distribution

The present-day distribution of animals in the world is highly complex. It becomes difficult to determine the distributional area of a particular species because of the mobility of animals. If we look into the areas of Arctic terns, these cover the whole world in one way or the other because their seasonal migration is so widespread that they are found in the Arctic region during northern summer whereas these reach as far south as South America and Australia during southern summer. Though there is no universal distribution of any species but there are some such animals which are cosmopolitan at least to limited extent and are found in more than one environmental conditions and habitats, for example, cyprinid fish (including carps, tenches, minnows etc.), frogs of genus Rana, perching birds (those birds which rest on trees), colubrid snakes (representing the species which is mostly found in United Kingdom), various types of rodents and man. It may be forwarded that a particular 'species' of animals may be concentrated in particular region but a 'genus' (including several species) many not be confined to a particular region rather it may be found in several faunal regions whereas a 'family' (consisting of numerous genera) may be found over many continents. It may be further pointed out that the distributional patterns of animals is dynamic and is subjected to continuous changes because of **speciation, extinction, dispersal** and **migration** of animals. Thus the continuity of distributional patterns of world animals is seldom maintained. Inspite of this fact there are some distributional patterns of animals at world level. The factors which control the distribution of animal species are divided into 2 groups.

(1) physical factors, and

(2) biological factors

1. Physical Factors

A particular animal species can live and flourish in a particular habitat because each species requires definite combinations of environmental conditions which favour their growth, speciation, colonization, reproduction and overall development. Temperature, moisture and humidity, water, sunlight, solar radiation, air pressure, gravity, topography, relief, slope and gradient, acidity, alkalinity and salinity of water, proportion of atmospheric gases, presence or absence of major minerals etc. are the important elements of physical factors which largely affect and control the distribution of animal species. The topographic features like distribution of land and water, mountains, plateaus, lakes and several erosional and depositional landforms and overall climate affect and control the distributional patterns of world fauna.

2. Biological Factors

Biological factors include the aspects of population ecology or ecological aspects of species population, interactions between animals and their physical environmental conditions, interactions among the animals themselves, interactions between animals and plants, mobility, migration and dispersal of animals. The important aspects of **animal ecology**, which affect and control the distribution of animals in any region, include abundance of animal populations, size of populations, regulation of population size and mutual interactions among the organisms and between the organisms and physical or natural environments.

The **abundance** of animals of a particular species is determined and controlled by the characteristics of a group of animals and not of the individuals e.g. density of animals (number of animals per unit area), birth and death rates, age distribution, growth forms, biotic potentials, group movement etc.

For example, migratory locusts are used to live most of their lives as solitary individuals. In other words, locusts normally do not live in clusters or groups but when there is sudden increase of harmones in their bodies their habit of living separately changes and they start living in groups and clusters and soon form aggregations at a particular place. This change in their habit triggers off change in their behaviour and the locusts resort to mass exodus in great migrating swarms. These mass movements of locusts in large aggregations are called **migratory swarms.** The visibility in the sky is reduced to minimum rather to zero when such large aggregations of locusts leave their places of initial breeding and fly in great swarms in the air to reach other places (fig. 11.6). Several types of distributional zones of locusts are formed over south-west and South Asia (Pakistan and north-western India) when the populations of locusts of Asiatic deserts and north-eastern Saharan desert change abruptly to form enormous aggregations and swarms into several adjoining areas. Consequently, four distributional zones of locusts are formed (fig. 11.6) e.g. (i) permanent zones of constant inhabitation which form the centres of periodic enormous aggregations, (ii) temporary zones of peak locust population, (iii) temporarily inhabited zones occupied by wandering great swarms of locusts mostly during summer months (mainly during mid-June to September), and (iv) the outer zone of swarming locusts where these are not able to reproduce by laying eggs. It may be pointed out that the locusts have great ability of reproducing within a single season. It is believed that if a pair of locusts is allowed to settle in the area it can produce a progeny of over 1,00,000 in a single summer season.

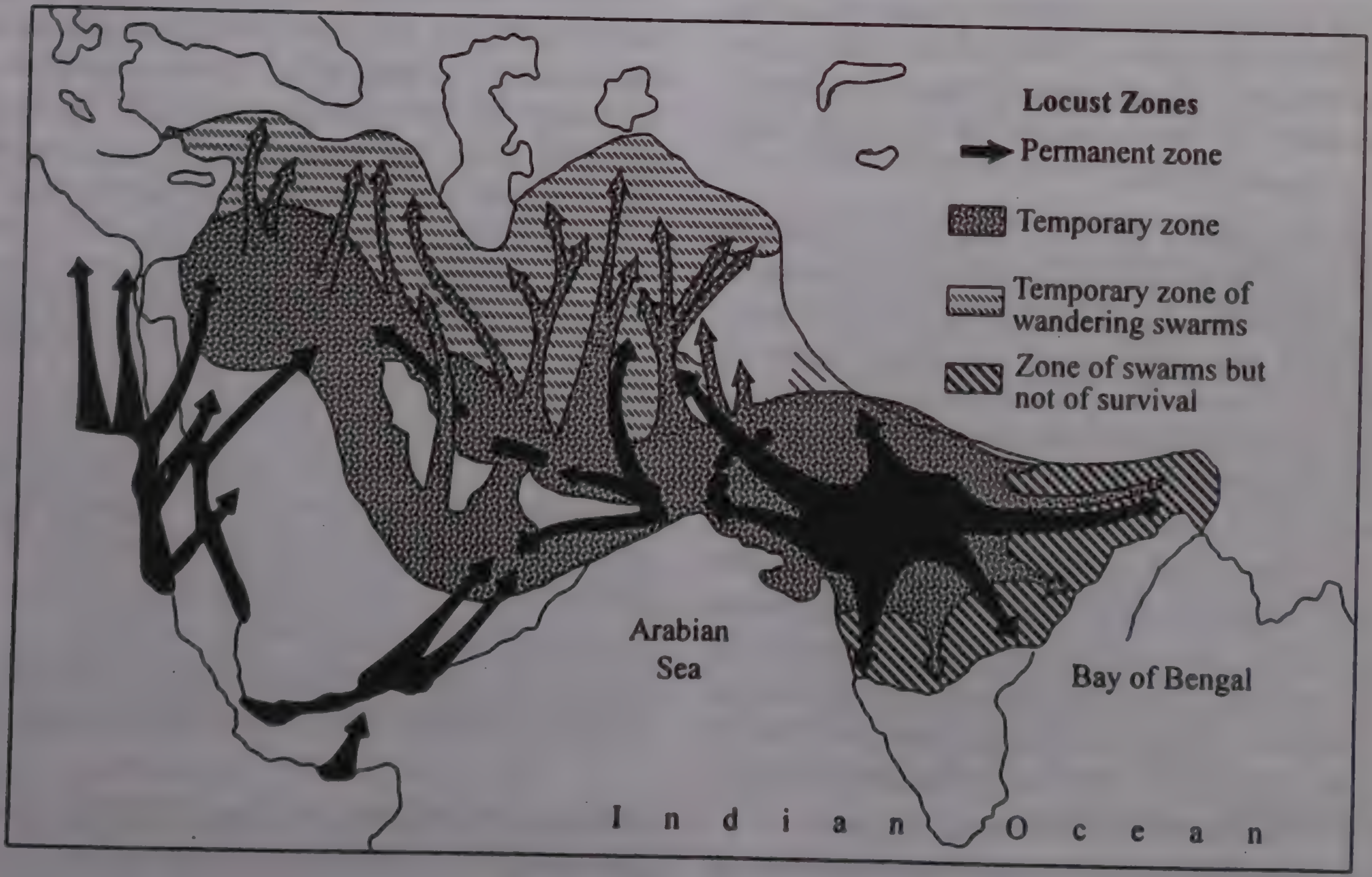


Fig. 11.6 : Aggregations and swarming of locusts (based on N.P. Naumov, 1955).

Such enormous locust swarms occasionally affect north-western India during July-August when 'Kharif Crops' (like maize, millets) are in growing stage. Here the visiting locusts have such an enormously high breeding rate that a pair of locusts can produce thousands of offsprings within 24 hours if they are allowed to sit on the soils and lay eggs. This is the reason that when migrating swarms are detected (as the sky in the west becomes red) the farmers rush to their crop-fields and use seveal devices to drive away the locusts.

Termites, ants and honeybees have also tendency to form clusters, groups or aggregations on sudden increase in their populations. Some animals like bisons also form groups and clusters whenever they are threatened by external sources. Some animals mainly birds and vertebrates develop the tendency of social organization or social grouping which results in phenomenal increase in their populations.

The animal populations are closely related to food chains. Normally, in any habitat the herbivorous animals of trophic level 2 (primary consumer) are largest in number and derive their food from the autotrophic green plants (primary producers which produce their own food through the process of photosynthesis) of trophic level 1. There is progressive decrease in the number of animals with increasing trophic levels.

The abundance and distribution of animals also depend on their typical behaviour. For example, there are such animals (like musk rats) which have high breeding rate but they do not return again to their breeding places. This typical behaviour (of not returning to breeding places) of some animals causes rapid rate of dispersal of their populations. On the other hand, there are some animals (like racoons) which have low reproduction rate but have the tendency to remain at their birth or breeding places for longer time. This typical biological instinct or behaviour restricts the dispersal and spreading of such animals but allows the abundance of animals in a particular area which results in the formation of groups, clusters or aggreations.

The **animal density** in a given area depends on birth rates, death rates, immigration (arrival of animals in a given area from other areas), emigration (migration of populations from a given area to other areas), age structure, dispersion etc. of animals. The density of population of animals in a given area increases when birth rate far exceeds death rates; major portion of the animal population consists of mature animals; immigration exceeds emigration; and the dispersion of animals from a given area is low.

There is a biological law that there is a capacity among the animals to grow rapidly. According to Thomas Malthus the populations (his concept is based on human population) go on increasing until they exceed their resource supply. Malthusian law of human populations further states that when the population of a given region or a country exceeds a critical limit (limit of supply of food resources) there is natural decrease in the population because of natural hazards and calamities and thus there is automatic regulation of population size. This is called **self regulation.** This law of human population also applies in the case of animal populations. According to this law, when the number of animal populations of a given species in a particular area exceeds the critical limit, its size is naturally controlled and regulated in accordance with the supply of food resources. It means that the population of a given animal species in a particular habitat is not allowed to exceed a certain limit. The self regulation of animal populations depends on decreasing fecundity or fertility and birth rate, increase in emigration (outward movement of animals from the concerned habitat), decrease in food supply due to increase in population, increase in death rate due to epidemics etc.

One case of self regulation of animal population may be presented in the following manner. If the population of insects in a specific area increases significantly beyond optimum level due to favourable climate, the food supply falls short of the demand of the increased insect population. With the result there is competition among the insects for food and many insects die of starvation and thus the insect population is brought back to its optimum size. Such type of self regulation of population size is also called as **density-dependent regulation.**

The **interspecific interactions** (interactions among the animals of the different species) and **intraspecific interactons** (interactions among the animals of same species) also affect the distributional patterns of animals. These ecological interactoins result in either phenomenal increase (**overcrowding**) or phenomenal decrease in animal population (**underpopulation**). The aforesaid ecological interactions may be negative or positive. Predation is the example of negative biological interaction because such interaction causes damage in terms of death by one group of animals to the other group of animals. This type of interaction thus controls animal population wherein the animal population in any region depends on **prey-predator relationships.** It may be pointed out that predation maintains equilibrium in animal population of any region. For exmaple, if all the predators are eliminated from any given region or if they are completely destroyed, the prey population will increase to such an extent that the region will have overpopulation. In the beginning of the present century the kaibab deers in the Arizona province of the U.S.A. were endangered by their predator animals, consequently the predators of kaibab deers were eliminated, which resulted in phenomenal increase in the population of kaibab deers and thus the ecological equilibrium was disturbed. If all the prey animals are eliminated by the predators when the former are eaten by the latter, predators also perish because of scarcity of food.

The various types of **biological interactions** which affect and control world distribution of animal population include (1) **competition** (wherein two or more species of animals compete in a given region for the same food resource and each species has a negative effect on the other), (2) **neutralism** (wherein several species live in a habitat but neither species affects the other species), (3) **inhibition** (where one species prevents the other species but the species which inhibits the other is not affected), (4) **predation/parasitism** (where the parasites or predator animals feed on other species of animals and thus prey animals suffer negative effect), (5) **mutualism** (when two species depend on each other for their survival and thus both are benefitted from each other), (6) **commensalism** (where two species feed together but one species known as commensal depends on the other and requires the other species to survive but the commensal species does not hurt the other speices), and (7) **protocooperation** (non-obligatory symbiosis-where two species benefit from each other but they can also survive separately).

The positive effects of biological interactions (when both the species or all the species are benefitted) result in the increase of animal population whereas negative effects control the population size of a region.

11.5 WORLD DISTRIBUTION OF LAND ANIMALS

If we look at the distribution of all animals at global level, the whole of the biosphere becomes a single distributional unit which represents the largest animal community. This single global pattern of all animal communities may be further sub-divided into two zoogeographical regions e.g.(1) **land/terrestrial zoogeographyical regions,** and (2) **aquatic zoogeographical regions.** Zoogeographical regions are also called **faunal regions.** The terrestrial or land faunal or zoogeographical region is further divided into several faunal regions at different levels. It may be pointed out that a single faunal region does not mean that it represents uniform distribution of all animals of a particular species, or family or order and the animals of a particular species or family are confined to a particular region alone, they are not found in other regions. In fact, speciation, migration, dispersal and extinction of animal species are natural biological processes and are active in each stage of animal evolution. These biological processes make the distributional patterns of world animals very complex. Inspite of this fact, there are certain common characteristics of animals which help in the identification and demarcation of faunal or zoogeographcal regions. The following facts must be taken into account while studying the world distributional patterns of the animals :

- Physical environmetnal conditions determine the number, abundance and diversity of animals. Maximum diversity is noticed among the vertebrate animals of the land and freshwater habitats of the tropical regions.
- There is zonal pattern in the world distribution of animals. This zonal pattern of the animal distribution is in two forms viz. (a) horizontal zones, and (b) vertical zones. Latitudes have maximum control on the horizontal zonal patterns of animal distribution because sunlight decreases from the equator towards the poles, which means there is corresponding decrease in vegetation and its diversity towards increasing latitudes and hence animal species diversity also decreases from the equator towards the poles. It may be further pointed out that the origin and evolution of animals first took place in the tropical or the equatorial regions from where

animals were dispersed to other areas. Thus the development of animal zones in the higher latitudes took place because of the dispersal and migration of animals from the animal zones of the tropical regions. Thus the horizontal animal zones of the higher latitudes are the result of the dispersal and migration of animals and various phases of speciation. For example, the development of temperate animal zone took place due to substraction of animals during their migration from the tropical zone.

- The animals have radiated in all directions from the centres of their origin. In other words, the animals have dispersed and migrated in all directions through various routes from the centres of their origin. Consequently, the distributional patterns of the world fauna are found in concentric zones.
- The diversity of animals of any region is the result of several phases of their dispersal and colonization.
- The concentration of animals could be possible only in the mammals whereas the distribution of other species of animals is more widespread and is not specific.
- The distributional patterns of all the animal species are not uniform because the distribution of same animal species is continuous while that of other species is discotinuous or disjunct. For example, the distribution of moose (a type of deer) is found in continuous zonal pattern in the taiga regions of North America and Eurasia whereas the distribution of azure-winged maggie, weather fish and bitterling is discontinuous as their two continuous distribution zones in middle and western Europe and in south-east Asia are separated by an extensive zone devoid of these animals.

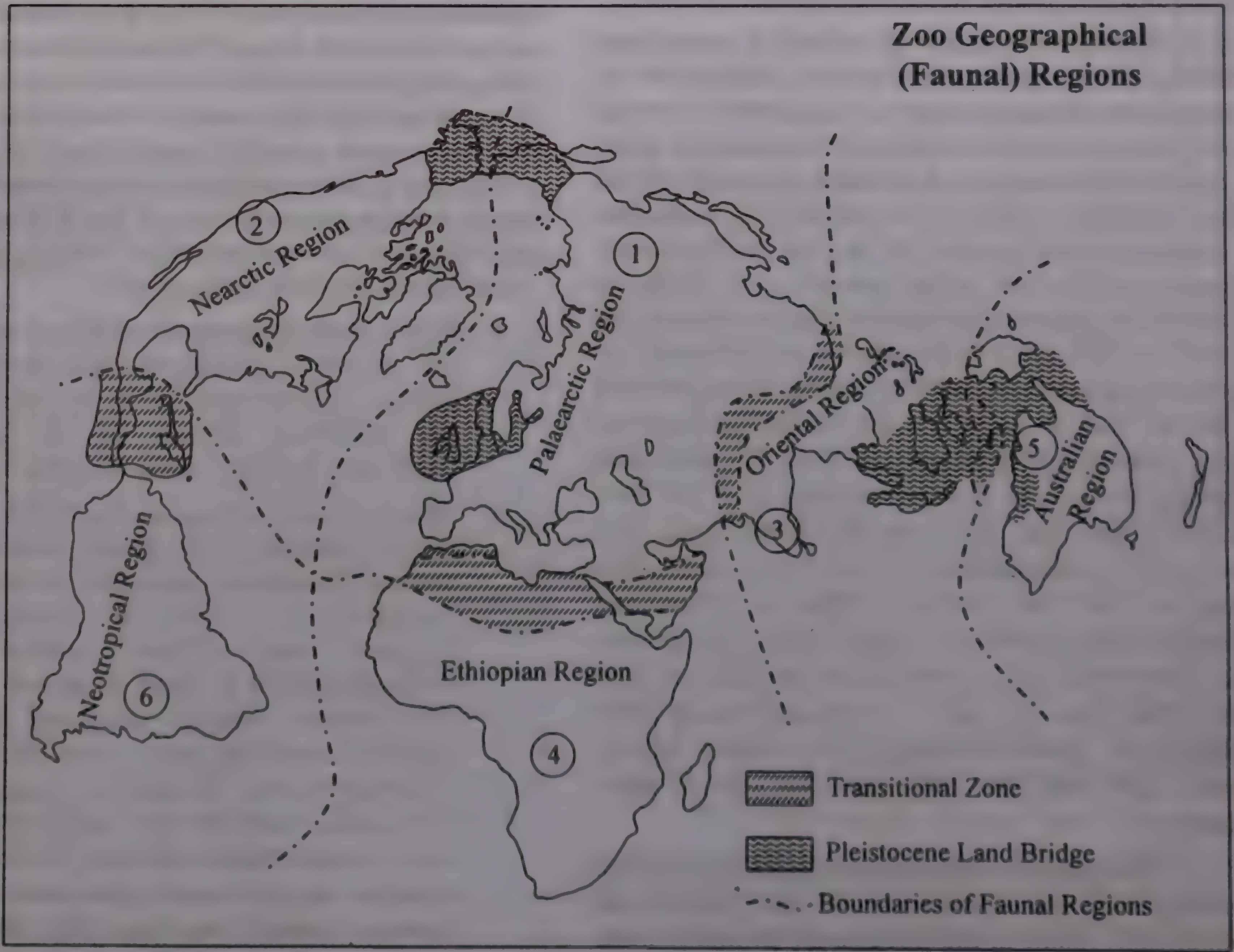

Zoo Geographical (Faunal) Regions
2
Nearctic Region
1
Palaearctic Region
Oriental Region
3
5
Australian Region
Neotropical Region
6
Ethiopian Region
4
Transitional Zone
Pleistocene Land Bridge
Boundaries of Faunal Regions

Fig. 11.7 : World distribution of land animals and major faunal regions of the world.

- Occeanic islands are characterized by special types of animals because there has been minimum migration and dispersal of plants and animals to the islands because of great oceanic barriers. Hawaii island, which was never connected with any landmass in the geological history of the earth, lacks in reptiles, amphibians, freshwater fishes and mammals (except one species of bats).

A.R. Wallace attempted the classification of world animals into faunal regions in 1876. Since then a number of attempts have been made to divide the world animals into fanual regions by several scientists e.g. P.J. Darlington (1957), S.C. Kendleigh (1961), W.George (1962), De Latin (1967), W.T. Neil and M.D.F. Udavardy (1969), De Laubenfels (1970), J. Illies (1974) etc. but still the division of world animals into fanual regiosns as presented by A.R. Wallace is the most convincing and acceptable among all the subsequent divisioins. Normally, the world is divided into the following 6 major faunal regions (fig. 11.7).

(1) Palaearctic region,
(2) Nearctic region,
(3) Oriental region,
(4) Ethiopian region, and
(5) Australian region.

1. Palaearctic Region

Palaearctic region includes Europe and midle and north Asia which represent 28 chordata families. The important animals of this great faunal region are Russian desmans, dormice of Eurasia, Mediterranean mole rats, saiga and chiru antelope (a type of deer), acentors, crocodiles, lizards etc. Reptiles are found in lesser number. This faunal region is further divided into 5 sub-regions on the basis of vegetation e.g. (i) **Tundra region** represents caribou, lemming, musk ox, Arctic hare, Arctic fox, wolf, polar bear etc.(ii) **temperate coniferous forest region** : moose, mule, deer, lynx etc. are the imporant animals of this region, (iii) **temperate grassland region** represents saiga, wild ass, horse, camel, jerboa, hamster, jackal etc,. (iv) **deciduous forest region** represents racoons, oppossum, red fox, black bear as important animals, (v) **desert region** : the important animals of this region are lizards, snakes, hamster, hedgehog, rat, jerboa, cottontail etc.

The palaearctic faunal region includes 136 families of vertebrate animals, 100 genera of mammals and 174 genera of birds. Besides, 3 unique families of vertebrate animals, 35 and 57 unique genera of mammals and birds respectively are also found in the palaearctic faunals region.

2. Nearctic Region

Nearctic region consists of the geographical territories of North America and Greenland. It is significant to point out that there is much similarity between Palaearctic and Nearctic faunal regions. Both the regions were connected through the Bering Land Bridge during Tertiary Epoch and Pleistocene period. This land bridge (fig. 11.4) enabled free exchange and migration of animals between these two regions which resulted into much mixture of animal species and therefore increase in species diversity. For example, American and European bisons reproduce after having sexual intercourses between them. Both the regions have salmons and trouts. On the basis of such biological similarities between Plaearctic and Nearctic regions, some scientists have grouped these two regions into one single region as **holarctic region**. It may be pointed out that in the beginning, horses, pigs, goats and sheep were not present in the Nearctic region but later on these animals migrated to North America from N.E. Asia through the landbridge of Bering Strait. The Nearctic region is characterized by a few special and typical animals e.g. pocket gophers, pocket mice, pronghorns, wild turkeys etc. Reptiles are found in large numbers. There are 122 families of all vertebrates, 74 genera of mammals, and 169 genera of birds. Besides, 12 unique families of invertebrates, 24 unique genera of mammals and 52 unique genera of birds are also found in this region. Nearctic faunal reigon is also divided like Palaearctic region into the following 5 sub-faunal regions on the basis of vegetation :

(1) **Tundra region** is characterized by the dominance of caribou, musk ox, lemmimg, arctic wolf, arctic fox, polar bear etc. It may be pointed out that the genera of the animals of Palaearctic and Nearctic faunal regions are the same but their species vary.

(2) **Temperate coniferous forest** includes moose, mule, deer, wolverine, lynx etc.

(3) **Temperate grassland region** is characterized by bison, pronghorn, jack rabbit, prairie dog, gopher, fox, coynote etc.

(4) **Deciduous forest region** includes racoons, oppossum, red fox, black bear etc. The genera of animals of deciduous forest regions of the Palaearctic and Nearctic faunal regions are almost the same but their species vary.

(5) **Desert region** is characterized by lizards, snakes, kangaroo, jerboa, hamster, hedgehog, cottontail etc.

3. Oriental Region

The oriental region includes the geographical areas of mainly south and south-east Asia. The Himalayas, Tibetan plateau and Chinese mountainous region form transitional zones between Palaearctic and Oriental faunal regions. Similarly, East Indes form transitional zone between Oriental and Australian faunal regions. The whole of this faunal region falls under tropical regions and hence this faunal region is associated with the Ethiopian faunal region. This faual region represents 164 families of all vertebrates, 118 genera of mammals and 340 genera of birds out of which there are 12 unique families of vertebrates, 55 unique genera of mammals and 165 unique genera of birds. This faunal region is characterized by the dominance of Indian elephants, rhinos, several species of deers, antelopes, pheasants, tigers, lizards, snakes, gibbons, monkeys, sunbear, porcupine etc. Tree shews, gibbon, orangutans and tapirs are the typical animals of the oriental faunal region.

4. EThiopian Region

The Ethiopion region incorporates substantial areas of the whole of Africa south of Sahara and far off south western Arabia which is separated from the African region by Red Sea. This faunal region also falls under tropical climatic region. Unlike other faunal regions, this region is characterized by minimum diversity of animals though there is complete absence of moles, beavers, bears and camels in this region. This region represents 174 families (22 are unique) of vertebrate animals, 140 genera (90 are unique) of mammals and 294 genera (179 are unique) of birds. This faunal region is further divided into 3 sub-regions.

(1) **Desert region** is characterized by the dominance of springbok, porcupine, jerboa, rock hyrax etc.

(2) **Savanna region** represents zebra, eland, gemsbok, hartebeest, gnu, giraffe, elephants, ostrich, lion, cheetah etc.

(3) **Tropical forest region** includes important animals like okapi, gorilla, chimpanzee, monkey, forest elephant etc.

There is similarity in a few animals of the Oriental and Ethiopian faunal regions like elephants, lions, cheetah etc. Hippopotamus, aardvark, ostrich and rodents and a few species of insectivorous animals are exclusively found in the Ethiopian faunal region.

5. Australian Region

The Australian region includes Australia, New Zealand and islands between S.E. Asia and Australia (such as New Guinea, Soloman, Samoa etc.). Some scientists do not include New Zealand in the Australian faunal region. There is difference of opinions among the scientists about the linkage of this region with the Oriental faunal region. This region is dominated by placental animals. Marsupials (characterized by pouch attached to the outer part of their abdomen) are the typical animals of the Australian faunal region. These animals carry their off-springs in their pouch which has feeding mechanisms. There are 141 families (22 are unique) of vertebrate animals, 72 genera (44 are unique) of animals and 298 genera (198 are unique) of birds. This faunal region is further divided into 3 sub-regions.

(1) **Desert region** is characterized by marsupial, mole, jerboa, parakeet, lizard etc.

(2) **Savanna region** is represented by emu, red kangaroo, bandicoot, wombat, cockatoo, parrot etc.

(3) **Tropical forest region** is dominated by tree and musk kangaroos, wallaby, koala, oppossum, cassowary, etc.

6. Neoarctic Region

The neoarctic region includes the whole of South America which is characterized by tropical environment. This region represents the largest number of exclusive mammals (which are not found elsewhere). About 32 families of marsupials (which are quite different from the Australian marsupials), and several typical and special families and genera of monkeys, birds and rodents are exclusively found only in this faunal region. There are 168 families (44 are unique) of vertebrate animals, 130 genera (103 are unique) of mammals and 683 genera (567 are unique) of birds in this faunal region. This faunal region is further divided into 3 sub-regions.

(1) **Temperate grassland region** is dominated by guanaco, rhea, viscacha, cavy, fox, shunt etc.

(2) **Desert region** is characterized by guanaco, rhea, armadillo, vulture etc.

(3) **Tropical forest region** is represented by monkey, kinkajoy, pygmy ant eater, sloth, tree snakes, parrot, humming bird etc.

Some scientists have assigned the status of minor faunal region to those islands which have been connected with the mainland (though this concept of isolation of some islands from the mainland throughout the geological history of the earth is still debatable). Such islands include Hawaii island, Greater Antilles, Madagascar and New Zealand. The solenodons and hutia family of rodents in Greater Antilles; tenrecs, lemurs, aye-aye, Malagasy mongooses and fossa, Malagasy rats and vanga shrikes in Madagascar and Kiwis, tustara, New Zeland frogs etc. in New Zealand are some of the important animals of such so called isolated islands.

11.6 DISTRIBUTION OF MARINE ANIMALS

There is wide range of variation between the distributions of land and marine animals because nearly all types of vegetations right from algae to tall trees are found over the lands whereas only phytoplanktons and algae of the bottoms of shallow seas are found in the seas and oceans. Land areas are characterized by several physical barriers (like high mountains, large inland water bodies, deserts, snow covered areas etc.) which hinder the dispersal and migration of animals from one region to the other region but there are no such barriers in the seas and the oceans, and therefore there is free movement of animals in the seas and the oceans which allows them to move for very long distances. As compared to the lands there is very little variation in the horizontal and vertical distribution of temperatures in the oceanic areas because the horizontal and vertical movements in the oceans mix the temperatures and thus try to maintain thermal homogeneity in the oceans.

Marine animals are divided into two groups on the basis of their life-forms e.g. (i) bottom living animals or **benthos,** and (ii) **floating animals** or **nectons** (fig. 6.1) which live in the photic zone of the oceans.

On the basis of temperature marine animals are divided into two groups e.g. (i) animals of the cold water, and (ii) animals of warm water.

It may be pointed out that the variation in the temperatures from equator towards the poles is confined to the surface oceanic water only because there is more or less uniformity in the temperature of increasing depths from equator towards the poles. There are larger number of marine animals in the photic zones of tropical seas and oceans than the cold regions. Secondly, the zonal patterns of the distribution of marine animals have developed only in the tropical seas and oceans. Thus four marine faunal regions of the tropical seas and oceans are determined on the basis of areal variations in their life-forms e.g. (i) Atlantic faunal zone, (ii) Indian Ocean faunal zone, (iii) Western Pacific Ocean faunal zone, and (iv) Eastern Pacific Ocean faunal zone.

The distribution of marine animals has been discussed in the next chapter (chapter 12, BIOMES, Marine Biome).

12

BIOMES

12.1 MEANING AND CONCEPT

The biosphere is divided into several natural **ecosystems** on the basis of life-forms of world vegetations. Such type of vegetation-dominated ecosystems are called **formations.** An ecosystem becomes **biome** when all the plants, animals and soils are studied collectively. In other words, a biome includes all plants, animals and soils of all those areas of the world where all the biota have minimum common characteristics and all the areas of biome are characterized by more or less uniform environmental conditions. Some scientists are not in favour of the inclusion of soils in any biome because the rate of evolution of soil is much slower than plants and animals. According to some scientists only the land plants and animals are included in biome because it is very difficult to demarcate marine biomes. Though a biome includes both plant and animals communities but green plants are more dominant because their total **biomass** is far more than that of the animals.

According to I.G. Simmons (1982) 'the most extensive ecosystem unit which it is convenient to designate is called **biome**'. Though a biome is studied in terms of its plant and animal communities but it also conforms with a definite distributional patterns of soils and climate. 'Thus the biomes of the world are major world-scale regions which integrate a number of factors into an intuitively recognisable whole-deserts, forests, savannas, oceans etc.' (I.G. Simmons, 1982). 'Although the biome includes the total assemblage of plant and animal life interacting within the life layer, the green plants dominate the biome physically because of their enormous biomass, as compared with that of other organisms. The plant geographers concentrate on the characteristic life-form of the green plants within the biome......the life-forms are principally trees, shrubs, lianas, and herbs but other life forms are important in certain biomes' (A.N. Strahler and A.H. Strahler, 1976).

It may thus be concluded that the **biome** is infact a large natural ecosystem wherein we study the total assemblage of plant and animal communities.

12.2 BIOME TYPES

World biomes are divided variously on different bases like climate, vegetation, soil-water condition, heat, growth form of plants. Basically world-biomes are divided into the following two broad categories on the basis of the nature of the habitats :

(1) land biomes, and

(2) aquatic biomes.

Land Biomes

1. On the Basis of Climate and Vegetation

Though there is variation in the evolutionary stages of plants and animals over lands and in aquatic environments but on an average there is close relationship between the world distributional patterns of plants and animals and the present climatic types of the world. Thus based on relationships between the distributional patterns of plants and animals and world climates the world biomes have been divided into the following 3 broad categories :

(1) Tundra biome,

(2) Temperate biome, and

(3) Tropical biome.

Since the vegetation is the most dominant component of the biomes and the vegetation and climates are very intimately related and hence the world is divided into different biome types on the basis of major world climates and vegetation types.

Thus biomes are divided into second order and third order biomes on the basis of vegetation types and characteristics as shown in table 12.1

Table 12.1 : World biome types based on climate and vegetation

Biomes of the First Order (based on climatic zones)	Biomes of the Second Order (based on vegetation)	Biomes of the Third Order
1. TUNDRA BIOME	(i) Arctic Tundra Biome	
	(ii) Alpine Tundra Biome	
2. TEMPERATE BIOME	(i) Boreal Forest Biome (Taiga Forest Biome)	(a) North American Biome
		(b) Asiatic Biome
		(c) Mountain Forest Biome
	(ii) Temperate Deciduous Forest Biome	(a) North American Biome
		(b) European Biome
	(iii) Temperate Grassland Biome	(a) Eurasian Steppe Biome
		(b) North American Prairie Biome
		(c) Pampa Biome
		(d) Australian Grassland Biome
	(iv) Mediterranean Biome	(a) Northern Hemispheric Biome
		(b) Southern Hemispheric Biome
	(v) Warm Temperate Biome	
3. TROPICAL BIOME	(i) Tropical Forest Biome	(a) Evergreen Rainforest Biome
		(b) Semi-evergreen Forest Biome
		(c) Deciduous Forest Biome
		(d) Semi-deciduos Forest Biome
		(e) Montane Forest Biome
		(f) Swamp Forest Biome
	(ii) Savanna Biome	(a) Savanna Forest Biome
		(b) Savanna Grassland Biome
	(iii) Desert Biome	(a) Dry or arid Desert Biome
		(b) Semi-arid Biome

2. On the Basis of Soil-Water and Heat Aailability and Growth of Plants

The land biomes are determined and divided into the following 3 major types and 13 sub-tyeps :

(A) Optimum land biome

Those land biomes become optimum biomes which are characterized by constant supply of soil water and heat throughout the year and the plants grow in all seasons of the year.

(1) **Tropical evergreen rainforest biome** represents the equatorial forest zones which are warm and wet throughout the year because of vertical sun's rays all year round and daily rainfall. There is water surplus throughout the year and the vegetation grows constantly in all seasons of the year.

(B) Biomes with seasonal climates

There are at least two seasons in a year when there is marked variation in temperature and humidity. At least one season is characterized by deficiency in either heat or humidity. There are seven types of biomes under this major class of biomes with seasonal climates as follows :

(2) **Monsoon forest biome includes** the open forest of tropical areas. One season is cool and dry while the other is warm and moist. There is deficiency of moisture during dry season and hence the plants shed their leaves at the end of winter season to conserve moisture. Thus the trees of this biome are deciduous in character.

(3) **Temperate deciduous forest biome** represents broadleaf deciduous forests of middle latitudes or of temperate regions. Plants shed their leaves during winter season. There is surplus soil water in this biome because of lesser evaporation due to relatively lower temperature than the tropical monsoon deciduous forest biome.

(4) **Coniferous forest biome** includes coniferous trees of the temperate climatic zones of high latitudes. These are evergreen forests. Winters are long and exceptionally cold and therefore there is deficiency of heat during cold months.

(5) **Mediterranean forest biome** represents the evergreen forests having stiff and hard leaves (sclerophyll forest) and very hard barks. Summers are dry but winters are wet. Thus there is deficiency of soil-water during dry summer months but the plants have been endowed with several typical characteristics to cope with dry summer months.

(6) **Savanna biome** is, in fact, tropical grassland having scattered trees, characterized by tropical climate with long dry season and short, wet monsoon season.

(7) **Tall-grass prairie biome** represents the region of mid-latitudes having dense and tall grasses and herbs and sub-humid climate.

(8) **Short-grass steppe biome represents** the steppe region of the Eurasia which is characterized by short and sparse grasses of semiarid plains of mid-latitudes and moderate soil-water deficit.

(C) Biomes with permanent deficiency in heat and/or water

On the basis of permanent deficiency in heat and or water world biomes are divided into the following 5 sub-types :

(9) semi-arid biome,

(10) warm arid biome,

(11) temperate arid biome,

(12) arctic tundra biome, and

(13) alpine mountainous tundra biome.

Aquatic Biomes

Aquatic biomes are divided into 3 major categories and 8 sub-types as follows :

(A) **Warm water biome**
  (1) continental shelf biome
  (2) open sea biome
(B) **Cold water biome**
  (3) upwelling water biome
  (4) continental shelf biome
  (5) open ocean biome
(C) **Fresh water biome**
  (6) riverine biome (river biome)
  (7) lacustrine biome (lake biome)
  (8) pond biome

12.4 MAJOR BIOMES OF THE WORLD

1. TROPICAL EVERGREEN RAIN-FOREST BIOME

Location and Extent

Tropical evergreen rainforest biome provides optimum environmental conditions for the growth and development of plants and animals because it is

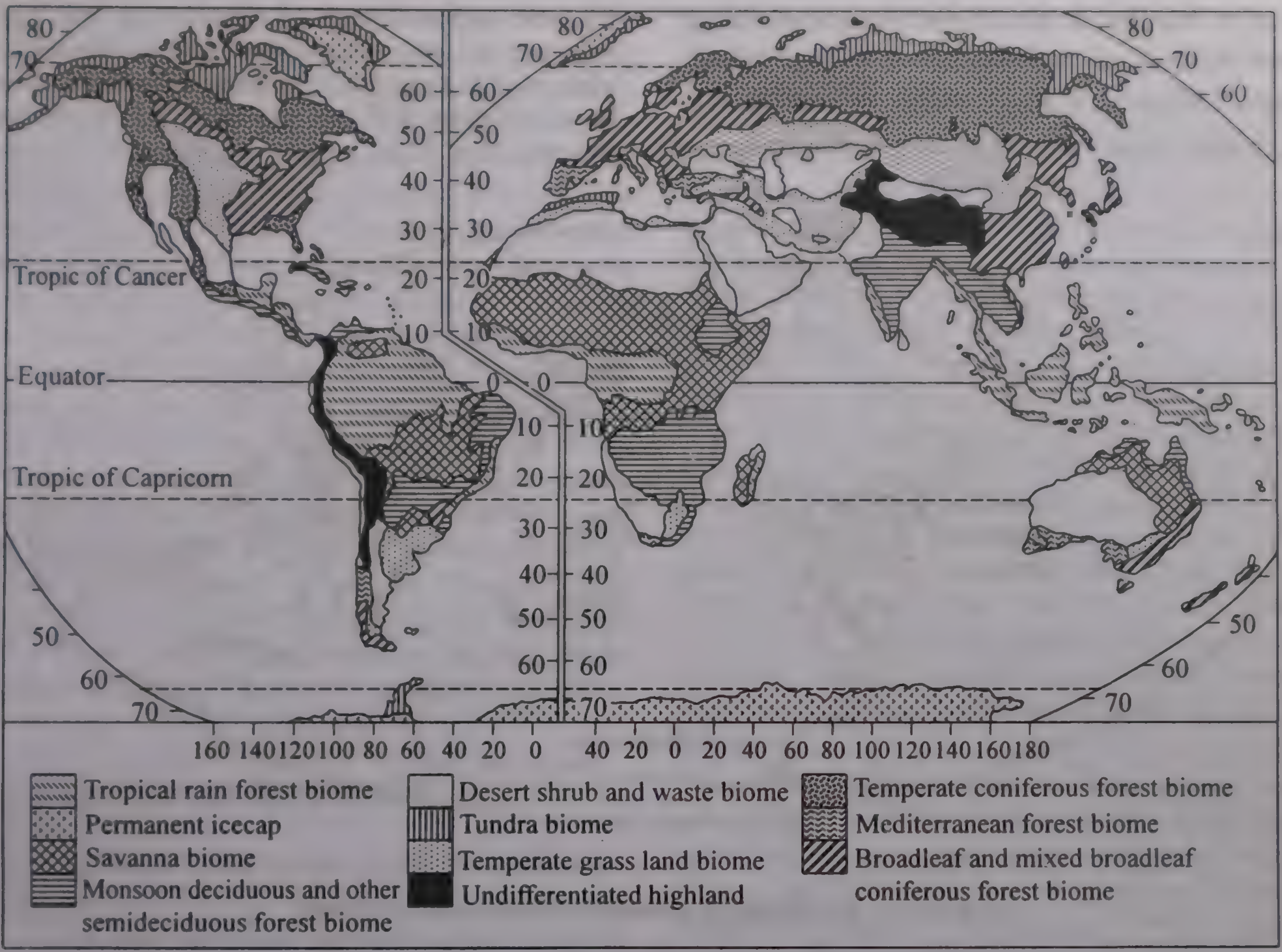

Tropic of Cancer
Equator
Tropic of Capricorn
80
70
60
50
40
30
20
10
0
160 140 120 100 80 60 40 20 0 40 20 0 20 40 60 80 100 120 140 160 180
Tropical rain forest biome
Permanent icecap
Savanna biome
Monsoon deciduous and other semideciduous forest biome
Desert shrub and waste biome
Tundra biome
Temperate grass land biome
Undifferentiated highland
Temperate coniferous forest biome
Mediterranean forest biome
Broadleaf and mixed broadleaf coniferous forest biome

Fig. 12.1 : Major biomes of the world.

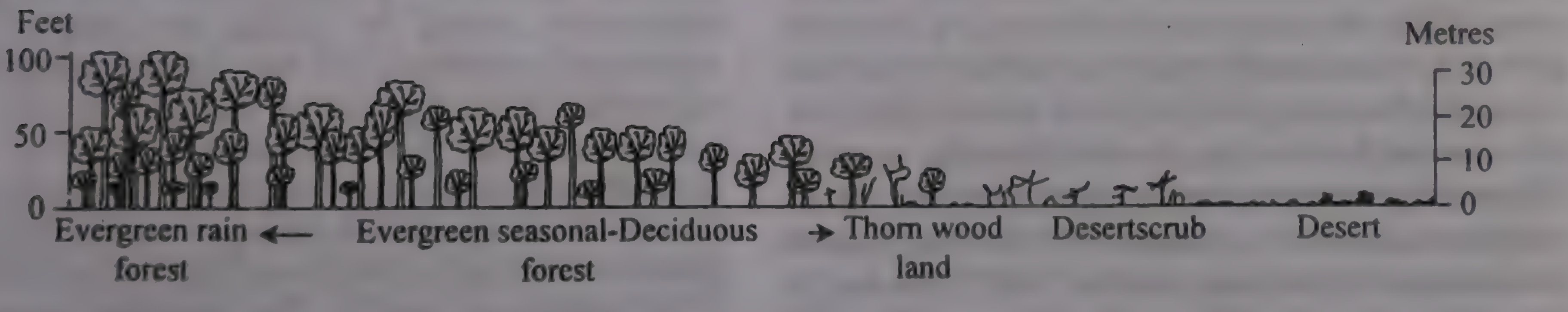

Feet
100
50
0
Metres
30
20
10
0
Evergreen rain forest
Evergreen seasonal-Deciduous forest
Thorn wood land
Desertscrub
Desert

Fig. 12.2 : The nature of vegetation in tropical biomes where vegetation changes from evergreen rainforests, through evergreen seasonal forests, monsoon deciduous forests, thorny woodland to desert scrub in accordance with the increasing aridity from equator towards the tropics.

characterized by high rainfall and temperature throughout the year. This biome is also called optimum biome because of uninterrupted supply of abundant moisture and water, and heat throughout the year which ensures continuous and normal growth of plants. Normally, the evergreen rainforest biome extends between 10⁰ N and 10⁰ S latitudes. The maximum development of this biome has taken place in Amazon Basin (South America), Congo Basin (Africa) and Indo-Malaysian Region (mainly in Java, Sumatra, Borneo, Malaysia and Guinea). This biome has developed, in fact, in true equatorial climatic region though in some areas the spatial coverage of this biome far extends beyond the equator. For example, it extends upto Vera Cruz in Mexico (about 19⁰ N) and upto 30⁰ S in South America (fig. 12.3)

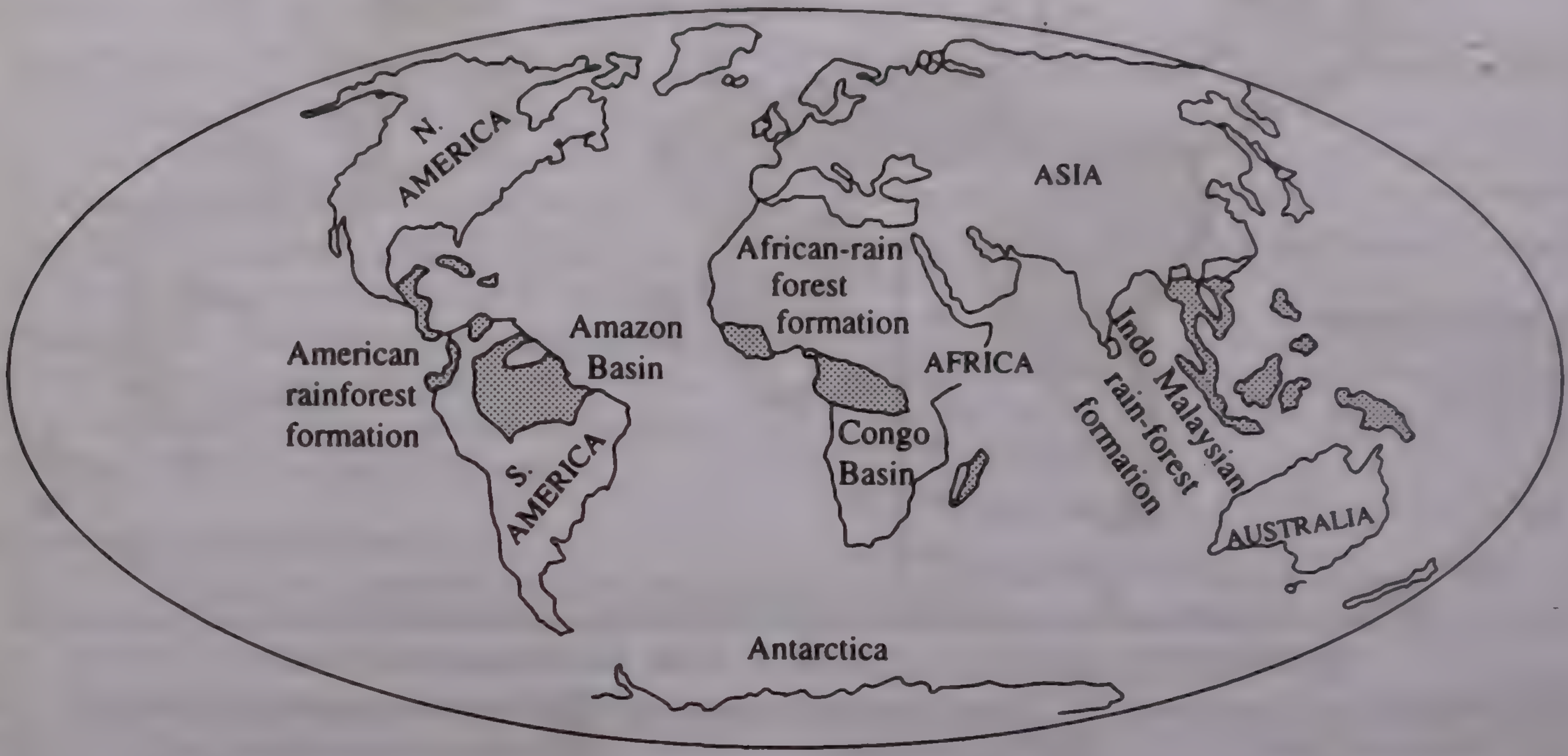

N. AMERICA
ASIA
African-rain forest formation
Amazon Basin
American rainforest formation
AFRICA
Indo Malaysian rain-forest formation
Congo Basin
S. AMERICA
AUSTRALIA
Antarctica

Fig. 12.3 : Distribution of tropical evergreen rainforest biome.

Climate

The average annual rainfall of most of the areas of the tropical evergreen rainforest biome is about 2000 mm or even more. Except 2 or 3 months generally every month receives rainfall of at least 200 mm. The aridity during a few months certainly increases with increasing distance from the equator. There is high temperature throughout the year. Mean annual temperature is around 20⁰C but the highest temperature of the year touches 30⁰C. The sun is more or less overhead throughout the year. There is very little difference between the lengths of day and night throughout the year. Annual range of temperature is around 1⁰C but the daily range of temperature varies between 5⁰C and 10⁰C. Most of the rainfall is received through convectional mechanism which yields heavy downpour through cumulonimbus clouds daily normally between 2 p.m. and 4 p.m.

The upper canopy of the tallest trees receives maximum sunlight whereas its amount decreases downward and it becomes minimum at the ground surface as there is complete darkness. This trend of progressively decreasing sunlight from the uppermost stratum to the ground stratum sets in keen competition among the various members of the vegetation community of the tropical evergreen rainforest biome for getting sunlight. It may be pointed out that the uppermost canopy is also covered by climbers and creepers and therefore the leaves of the uppermost canopy receive only 25 percent of the total sunlight reaching the top surface of the uppermost canopy. The underlying areas of the tree canopy receive only 3 percent of total sunlight. Wind speed also decreases downward from the upper most canopy and it becomes almost zero at the ground surface but the moisture content in the air increass from the uppermost canopy downward to the ground surface because evaporation also decreases downward.

Almost absence of sunlight at the ground stratum results in the development of very few leaves and flowers of plants. The germination of seeds and growth of seedlings and sapplings are exceedingly slow because of the pacucity of sunlight on the forests floor. There is maximum inerception of falling rains by the uppermost canopy of the forest cover and thus the intercepted rainwater reaches the ground through the leaves, branches and stems of trees and other plants in the form of **aerial streamlets** which allow maximum infiltration of rainwater in the ground surface. The interception of rainwater by the uppermost ıorest canopy also allows much evaporation of intercepted rainwater because the rainwater is held at the outer surfaces of the leaves. Only one third of the total rainfall received at the uppermost forest canopy reaches the ground surface. It is obvious that the vegetation has been controlled and determined by the typical characteristics of equatorial climate and in turn the vegetation has given birth to tropical micro-climates in several strata of the vertical structure of the vegetation community of the tropical eergreen rainforest biome.

Vegetation Species Composition

The tropical evergreen rainforest biome accounts for the largest number of plants species. Though there is almost uniformity and similarity in the life-forms and the structure of the plants in all parts of this biome but there is much variation in the composition of plant species. There are numerous species of plants in various parts of the tropical evergreen rainforest biome. For example, 6000 to 7000 species of flowering plants in the western Africa (Congo Basin); 20,000 species of flowering plants but quite different from the western Africa in Malaysia; 40,000 species of flowering platns in Brazil and 2000 species of flowering plants in Panama Canal Zone have been identified. It will be virtually impossible to present all the species of plants by names if all the species of all plants of the tropical evergreen rainforest biome become known to the botanists.

Tree is the most significant member of the tropical evergreen forests. The number of tree species is so large and their diversity is so great that one hectare of land in the equatorial region accounts for 40 to 100 species of trees. It may be pointed out that tree species account for 70 percent of the total plant species of the tropical evergreen rainforest.

Creepers (climbers) are the second important floral members of the rainforests. These belong to the category of **vines** and range in form from fine string-like stems to massive cable-like forms. These creepers are so circuitous and highly irregular in form that it becomes difficult to find out their actual lengths. 'They ramble through the forest, scaling the highest emergent trees and frequently looping down to the ground and then ascending further sections of the forests. In the constant struggle for light, climbers have developed this mechanisms for reaching the high insolation areas with the investment required for a large supporting biomass' (P.A. Furley and W.W. Newey, 1983). The climbers thus so greatly bind several trees and plants together that the accessibility in the forest cover becomes almost zero. This typical structural form of the tropical evergreen rainforest has also affected the form of animal life (to be discussed in the succeeding section). It may be poited out that the tropical rainforests account for 90 percent of all climbing species.

Climbers are divided into two major groups as presented by P.W. Richards (1952) e.g. (1) Climbers of the lower strata of the forests include herbaceous plants, and (ii) Long woody climbers known as **lianas** are found in all strata (right from the ground stratum to the uppermost stratum of forest canopy) of the forest. Lianas are the most significant members of the climbers or creepers. The lianas are characterized by thick woody stems of 20 cm or ever more, longer lengths upto 240m or even more and large crowns of numerous leaves sometimes resembling the crowns of trees. Besides, (iii) a third type of tropical climbers has been also identified i.e. the **epiphytes** which do not have their roots on the ground surface, rather these are evolved on the trunks, stems, branches and leaves of trees, shrubs and herbs, climbers etc. The epiphytes live in almost all the strata or layers of the forests and they do not require climbing ability as they grow upward and reach the uppermost canopy of the forest in search of sunlight. These epiphytes provide certain habitats to micro-organisms such as planarians, earthworms, snails, woodlice, millipedes, centipedes, termites, ants, grasshoppers, earwigs, scorpion, snakes, tree frogs, lizards and a host of insect larvae.

Epiphytes are further divided into 4 subtypes on the basis of their morphology as presented by S.A. Cain and G.M. de Oliveiro Castro (1959) e.g.

(i) **holo epiphytes,** the roots of which never reach the ground surface; (ii) **hemi-epiphytes** are first evolved on the branches, trunks and stems of trees and grow upward but ultimately their roots reach the ground surface and are thus established in the ground and take the form of climbers; (iii) **pseudo-epiphytes** first evolve in the ground and grow upward to establish themselves on the branches and stems of trees. After the pseudo epiphytes are established on the trees, their roots disappear but their upper parts are maintained; (iv) **semi-parasite epiphytes** are those climbers which get their food from other autotrophic plants.

Epiphytes are also divided on the basis of their forms e.g. (i) macro-epiphytes which include several types of ferns and shrubs of angiosperms such as orchidaceae, bromeliaceae, asclepiadaceae etc. and (ii) micro-epiphytes which include moss, lichens, algae etc.

It may be pointed out that the aforesaid two major members of the tropical rainforest biome viz. trees and climbers are autotrophic green plants which manufacture their own food through the process of photosynthesis but there are other numerous parasite and saprophyte plants in this biome.

Vertical Stratification of Vegetation

The vertical stratification of vegetation community means the composition of plant assemblages from the soil surface or ground surface to the uppermost forest canopy. Thus the different strata of the vertical profile of plant community in a given region represent diferent layers of habitat (niche) of different plant groups. 'Stratification results from competition between species for favourable locations which, in turn, exerts control over microclimate and other factors affecting the habitats of plants and animals' (P.A. Furley and W.W. Newey, 1983). There are five layers or strata from the ground surface to the uppermost canopy of the tropical evergreen rainforest biome out of which three upper layers consist of trees (fig. 12.4).

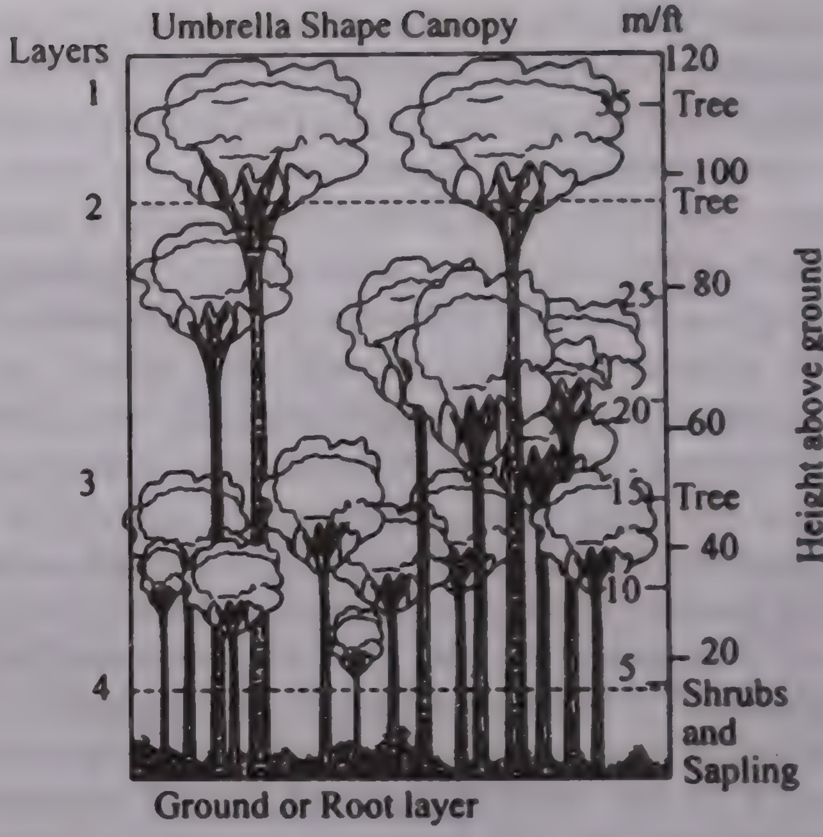


Fig. 12.4 : Vertical stratification of the tropical evergreen rainforest biome.

(1) **First (top) layer (stratum)** : represents the uppermost canopy of the tallest trees of the forests. The top surface of the uppermost stratum is like an umbrella but the level of the top surface is not uniform, rather it is discontinuous and wavy in character. This layer receives maximum amount of sunlight and intercepts the rain drops. The height of the tompmost layer ranges between 30 m and 60 m. This layer is also called as **dominant layer.**

(2) **Second layer** : is formed below the uppermost layer (top layer) of the forest canopy at the height of 25 m to 30 m. It is also called as the **codominant layer** or the second dominant layer. The upper crown of this layer is mop-shaped.

(3) **Third layer** : is formed of lower and smaller trees, the crown of which is at the height of 15-20m from the ground surface. The trees of this layer have a typical characteristics of their leaves in that they (leaves) are much larger than the leaves of the aforesaid first two layers because of the fact that these larger leaves can trap more sunlight which is very low in this layer.

(4) **Fourth layer** : represents the shrub layer which is below the aforesaid three layers. This layer is not continuous rather it is fragmented and sporadic in nature. This layer also includes the saplings but these are not permanent members of this layer. This **herbaceous (shrub) layer** also includes some pygmy (dwarf or stunted plants and trees) trees but of less

than 5m height. The crown of this layer is usually 5m from the ground surface.

(5) **Ground layer** : represents the plants growing at the ground surface but seldom gains height of more than a metre or two. This layer is dominated by herbaceous plants and fern. These herbaceous plants do not form dense cover and have fewer species because the absence of light does not allow much growth of herbaceous plants.

Animal Community

There are some unique characteristics of animals of the tropical evergreen rainforest biome which are not observed in other biomes e.g. (i) There is regular growth of plants throughout the year and therefore there is regular and constant supply of abundant food for the animals, with the result they have not to migrate for food. In other words, the animals of the tropical evergreen rainforest biome are least mobile, (ii) The forest is full of animal activities throughout 24 hours i.e. throughout day and night because animals of different species live in various vertical strata of the forests. Some animals are active during day time while others are active during nights. It is very unique but interesting feature of the rainforests that there is always hue and cry which makes this biome alive.

P.W. Richards (1970) has presented a very stylish and poetic description of the diurnal rhythmic activities of different animals living in different strata of the rainforest of South America. During day time the biological environment of the lowest stratum or the ground layer is made lively through the activities of several species of deers like brocket deer, coatimundis (a South American herbivorous animal), and agoutis while howler monkeys jump from one branch to the other branch of small trees. The upper strata are made lively through the activities of curassows (a type of South American bird), tinamous (a type of bird) and numerous colourful humming birds and numerous butterflies make the environment of the lower strata very soothing and charming while numerous lizards and other climbing animals move vertically along the stems and branches of trees of different vertical strata. Several animals like silky ant eaters, woolly oppossum, kinkajous, armadillos, and several predators ranging from jaguars to owls are busy during night for getting their food. The mornings and envenings are always made lively and vibrant by the noise of several animals and birds like howler monkeys, parrots, parakeets, tree frogs and numerous types of opthoptera. Thus it is obvious that the animals make the tropical evergreen rainforests always alive day and night.

It may be pointed out that the vertical stratification of the rainforest biome has largely affected the life-forms of animals living in the different layers (strata) of the forests. Most of the animals are **arboreals** (tree living) and thus they have been provided additional features by the nature to climb the trees like claws, adhesive pads, fingers, toes and several clinging mechanisms. Some animals have developed the ability to glide in the air e.g. fox, tree frogs, squirrels, tree snakes etc. The ground animals have to pass through the dense and thick covers of trees, shrubs and climbers and thus they have aquired special qualities to make their way through the forests viz. (i) Mammals have generally larger and sturdy bodies so that they can move by pushing thickets of plants away. Such animals include chimpanzee, gorilla, bison, African elephant, ocapi, leopard, numerous genera of pigs etc. (ii) Some ground animals are very small in size but are very much mobile and clever so that they can pass through dense vegetation. (iii) The third category of ground animals includes hidden small organisms belonging to the group of **cryptozoic animals.** Such organisms live beneath stones, logs, dead branches of trees, parts of trees, litters of leaves etc.

The number, density and diversity of animals in the tropical evergreen rainforest biome increase from the ground layer towards increasing strata (layers) upward because of the fact that food supply also increases upward from the ground stratum due to increasing trend of sunlight in the same direction. It may be remembered that the green plants manufacture their food through the process of photosynthesis which requires sufficient amount of sunlight. It is obvious that the vertical stratification of the rainforest has given birth to well organized vertical stratification of animals. J.L. Harison (1962) has identified the following strata of animals and their important members from the uppermost stratum to the ground stratum.

(1) **Upper air animals community :** The upper surface of the canopy of the topmost stratum of the rainforest is dominated by insectivorous birds and bats but a few species are also carnivores. These birds belong to the category of fast flying species such as Asian falconet, swifts, seviftlet etc.

(2) **Main canopy animal community** : includes those birds and fruit bats which live in the canopy of the tallest trees forming the uppermost stratum. The important animals of the tompmost canopy of the Amazonian rainforest are toucans, parakeets, barbets, cotingas, curassows, bill birds etc. A few small mammals, such as squirrels, herbivorous monkeys etc., are also found in the topmost stratum.

(3) **Middle zone flying animal community** : includes mostly flying birds and insectivorous bats.

(4) **Middle zone climbing animal community** : The animals of this zone have various climbing mechnisms and they reach the topmost stratum through the stems and brancehs of trees and climb down to the ground stratum. These belong to both categories of carnivorous and herbivorous animals. Squirrels and civets are the important members of rodents which belong to the category of mammals. The binding, circuitous and criss-crossing networks of various types of climbers facilitate easy movements of these climbing animals through all the vertical strata. These creepers also provide ideal habitats for these animals.

(5) **Ground zone large animal community** : includes mostly animals but there are also some birds in the ground stratum. These animals have large but sturdy bodies and lack in climbing qualities and mechanisms. The herbivorous large animals are few in number, important being mouse deer and cassowaries. Numerous members of pig family feed on roots, tubers and bulbs. It may be pointed out that the largest animals of the tropical rainforests are smaller in size than their counterparts in other open forests and grasslands because here the ground animals have to pass through dense vegetation cover and therefore they have been provided relatively smaller bodies but with great power and strength so that they can make their ways through dense forest. For example, the forest elephants of the rainforest biome are much smaller in size than the bush elephants and savanna elephants.

(6) **Ground zone small animal community** : includes small animals and micro-organisms. Most of these animals are insectivorous such as argus pheasant, peacocks and numerous types of fowl such as Guinea fowl.

Ecological Productivity

The primary ecological productivity of the tropical rainforest biome is the highest of all biome types of the world. It may be pointed out that the rainforest biome represents only 13 percent of the total geogrpahical area of the world but this biome accounts for 40 percent of the total **net primary productivity** of the world. The average net primary production of this biome is 5000 dry grams per square metre per year. Wood constitutes the largest share of the total biomass and net primary production. There is maximum competition among the various members of vegetation communities of the tropical evergreen rainforest biome to get light. Thus it is obvious that the plant species of almost similar characteristics and features can survive in this competition. This is the reason that inspite of largest number of plant species in this biome they have more or less similar life-forms.

The maximum ecosystem productivity is because of availability of sufficient sunlight and humidity (water) throughout the year. It may be remembered that these two are the primary requirements for photosynthesis by green plants. It is thus apparent that two basic parameters of high mean monthly temperature (radiant energy) and rainfall is fully reflected in the luxuriant growth of tropical evergreen rainforests and their maximum primary productivity.

Human Interactions

The human interaction with tropical (equatorial) rainforest biome has not been harmonious rather it has been and is exploitative and destructive. Man has started to damage this biologically richest ecosystem through his economic activities. A sizeable portion of Amazonian rainforests has already been damaged through mining activity and industrial and agricultural expansion. The construction of large dams and reservoirs on the Amazon and its tributaries at the cost of rich forest cover has upset the ecological balance of the area. The powerful elite society and even the local Brazilean government is not paying any attention to the mass movement of the local aborigins against mas felling of trees.

2. MONSOON DECIDUOUS FOREST BIOME

LOCATION AND EXTENT

Normally, the tropical deciduous forests are found in the regions of monsoon climate but there are some departures from this close relationship and near correspondence between the regions of monsoon climate and deciduous forest. There are three major areas of tropical deciduous forest biome viz. (i) the Neotropics mainly West Indes, (ii Indo-Malaysian Zone (mainly in south and south-east Asia except equatorial evergreen rainforest areas), and (iii) Eastern Africa and northern Australia. Besides these major areas, some discontinuous localities of tropical deciduous forest biomes are also found in South Africa, Southern Brazil, South-Eastern U.S.A., Formosa (Taiwan), southern China and Japan (fig. 12.5).

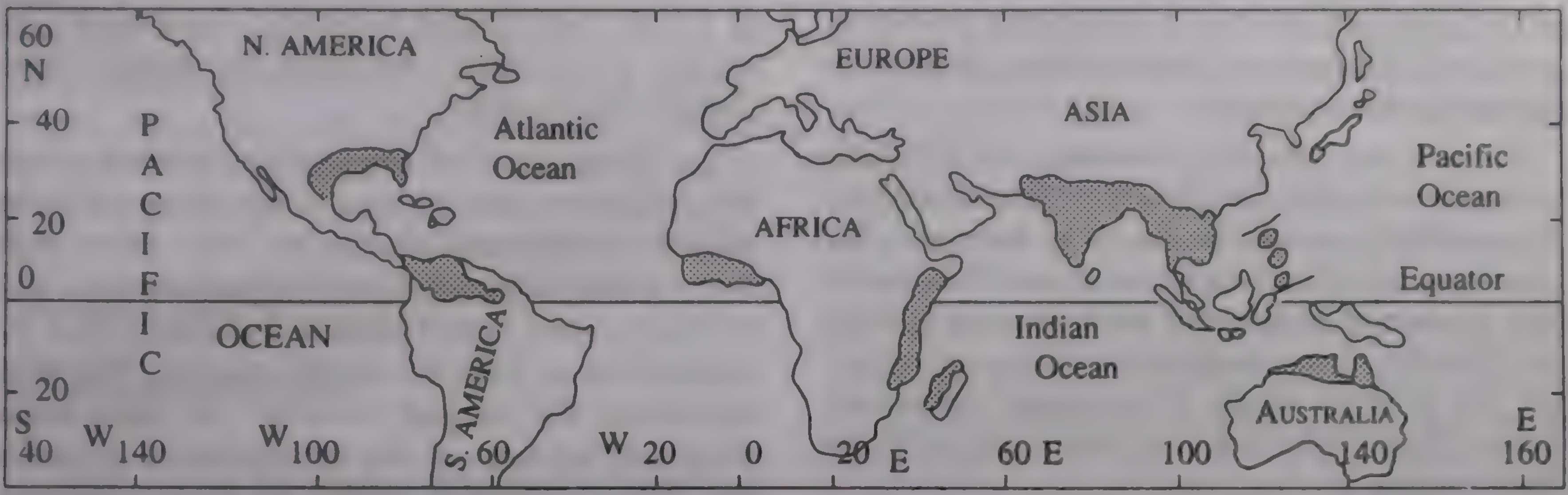


Fig. 12.5 : Distribution of Monsoon deciduous forest biome.

Climate

This tropical deciduous forest biome is charaterized by two distinct seasons viz. moist season and dry season. There are three main seasons in a year in India and surrounding monsoonal areas such as Pakistan, Bangladesh etc. e.g. (i) dry warm summer season (March to June), (ii) warm humid summer season (July to October), and (iii) dry winter season (November to February). Average temperature of warm dry summer season ranges between 27^{0}C and 32^{0}C but the maximum temperature ranges between 38^{0}C and 48^{0}C during May and June. Warm humid summer season records average temperature between 20^{0}C and 30^{0}C. The temperature during dry winter season ranges between 10^{0}C and 27^{0}C. The length of dry season is more important than the total amount of precipitation in affecting vegetation in the tropical deciduous forest biome.

On an average the mean annual rainfall is around 1500 mm but there are much variations in temporal and spatial distribution of rainfall. Some times a few areas receive even less than 500 mm of mean annual rainfall. Even the temporal distribution of rainfall within a single year is highly variable because more than 80 percent of mean annual rainfall is received within 3 wet months of summer season (July, August and September). Thus the rainy season records much surplus water whereas dry winter and summer seasons have marked deficit water because dry season receives less than 25mm of rainfall per month. There is maximum evaporation during warm dry summer months which results in desiccation of soils and marked reduction in soil water. This seasonal regime of annual monsoonal rainfall gives deciduous character to the vegetations which shed their leaves (mostly trees and shrubs) during the transitional period between winter and summer season.

Plant Community

The number of palnt species is less in the tropical deciduous forest biome than the tropical evergreen rainforest biome. Since the density of plants is also lower in this biome than the rainforest biome and hence there is comparatively less competition among the plants for getting sunlight. The height of most of the trees ranges between 12m and 30 m. There are four strata or layers in the vertical structure of the tropical deciduous forests. The uppermost and the second strata consist of trees, the third stratum is formed by shrubs whereas the last and the fourth stratum or the ground stratum represents herbaceous plants.

Most of the trees are deciduous but the shrubs of the third stratum are evergreen. The trees are characterized by thick girth of stems, thick, rough and coarse barks and large hydromorphic leaves or small, hard xeromorphic leaves. The large hydromorphic leaves enable the trees to trap more and more rainfall during wet seasons but these large leaves are shed in dry period to conserve moisture whereas small and hard xeromorphic leaves enable the trees to withstand dry weather and water deficiencies.

Though there are numerous climbers mainly **lianas** and **epiphytes** but their numbers are far less in the tropical deciduous forest biome than the tropical evergreen rainforest biome.

Sal (Shorea robusta) and teak trees of Indian deciduous forests form forest canopy but its shape is not like umbrella or cauliflower as is the case with the forest canopy of the rainforest biome. Bamboo is another important member of the Indian deciduous forests. Besides, there are numerous trees, climbers, shrubs and grasses which have spatial variations from one region of the tropical deciduous forests to the other region.

Animal Community

It may be pointed out that various dimensions of animal community of any habitat/ecosystem/biome including the number of species, their populations and density, their life-forms and various activities, reproduction and various types of biological interactions and above all species diversity largely depend on the composition and structure, richness or poorness, total biomass etc. of vegetation communities of the concerned biome. It is a significant ecological principle that more is the development of stratification of the vertical structure of the vegetation community of a biome and greater the number of plant species, the more will be the number of animal species, their total population and species diversity. This ecological principle holds good in the case of tropical evergreen rainforest biome as discurssed earlier. But there are comparatively lesser number of animal species in the monsoon deciduous forest biome than the rainforest biome because of comparatively less developed vertical strata and hence less diversification of animal species.

The seasonal character of vegetation community in terms of dense vegetation cover, full development of leaves and their evergreen form during rainy months (wet summer season, July to September) and shedding of leaves, drying of herbaceous plants etc. during dry season mainly during dry warm season has affected and determined the seasonal behaviour of animal communities particularly breeding and migrating behaviour. In other words, the seasonal charater of the monsoon deciduous forests has been responsible for the seasonal regime in the breeding and reproduction and migration of animals. For example, birds in east Africa breed twice during the two different seasons of a year. Indian dogs generally breed once a year mainly at the end of wet monsoon season (during October-November).

The animals of the tropical and sub-tropical dry deciduous forest biome range from very small animals (micro-organisms) to very large-bodied animals like elephants, horses, hippopotamus, ganda or rhinos, lions, forest buffalo together with a large populations of birds of several species. This biome represents the largest number of domesticated mammals because of the development of agriculture. This biome also carries the largest number of human population of the world.

Human Interactions

The tropical and sub-tropical monsoon deciduous forest biome is one of the most disturbed ecosystems of the world. The forests have been adversely affected by both natural and anthropogenic processes. There are numerous cases of frequent forest fires every year kindled by either natural processes such as lightning or anthropogenic factors such as inadvertent actions of man (throwing of burning ends of 'bidi' or cigarettets by the herdsmen in the forest) or advertent and intentional actions of man (such as clearing of forests through deliberate burning for agricultural purposes under **jhum cultivation** (which is very much prevalent in India) and large-scale grazing. The forests of the monsoon deciduous forest biome have been so rapidly destroyed within the last 50 years or so through the rapacious utilization of forest resources for commercial and industrial purposes and large-scale clearance through mass-felling of trees for agricultural land that the vegetation cover has shrunk to a very critical size.

The rapid rate of deforestation has led to the initiation of several ecological and geological problems. Several species of precious animals have now become endangered species because of destruction of their natural habitats. For example, lions and tigers and even elephants have become endangered species in India partly because of deforestation and partly by mass hunting of these animals. Similarly, Indian rhinos are facing extinction because of their mass killing. The lions of Gir forest of Gujarat of India together with other animals like leopards, spotted deer, sambhar, deer, Indian gazelle, nilgai antelope, wild boar etc. are now endangered species because of enormous destruction of the Gir Forest Ecosystem. The rapid rate of deforestation in the monsoon lands mainly in India has caused accelerated rate of soil loss through rill and gully erosion, silation of river beds and consequent recurrent severe floods in the alluvial rivers.

3. SAVANNA BIOME

Location and Extent

The word **Savanna** has been used for different meanings by various scientists e.g. the word 'savanna region' has been used by the climatologists to indicate a particular type of climate i.e. tropical wet and dry climate (Aw climate of Koppen) as savanna climate, while the botanists have used the word savanna for a typical type of vegetation community of the tropical regions characterized by the dominance of grasses. Normally, the Savanna biome refers to that vegetation community of the tropical areas which is characterized by the dominance of ground cover by partially xeromorphic herbaceous plants, upper stratum of scattered trees and middle layer of sparse shrubs. This Savanna biome extends in both the hemispheres between 10^0-20^0 latitudes and includes **Llanos** of Columbia and Venezuela; South-Central Brazil, Guiana, Paraguay (all in South America); hilly areas of the Central America; Central and East Africa (maximum extent in Sudan); Northern Australia and some areas of India (the Savanna of India is not the original and natural vegetation cover rather it has developed due to human interference with the original forest cover resulting into the development of widespread man-induced grasslands) (fig. 12.6).

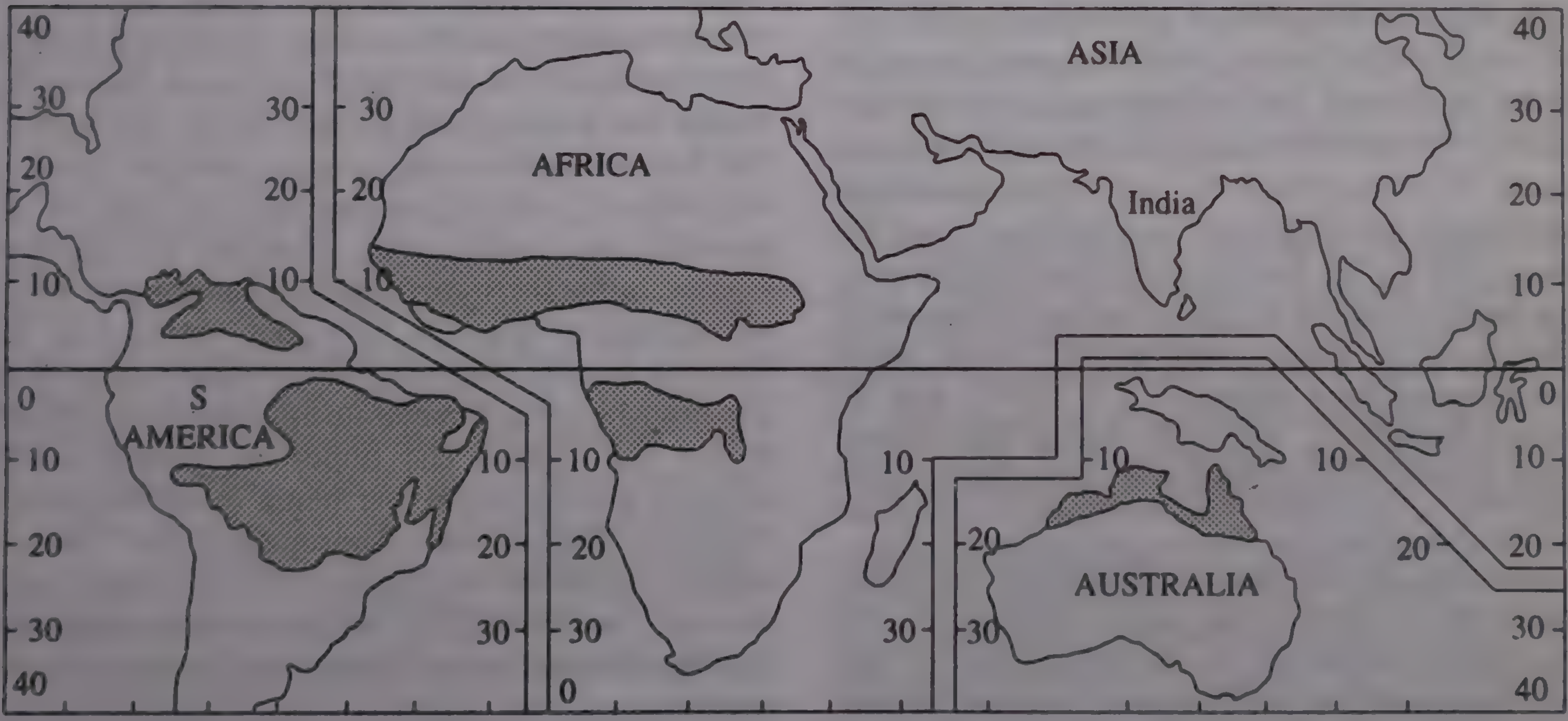


Fig. 12.6 : Distribution of Savanna Biome.

There is no unanimity of views of the scientists about the origin and evolution of savanna grassland biome. According to the majority of the scientists the savanna biome is the result of interference and modifications in the natural environments of the regions now considered as Savanna region by man himself (human activities like deforestation, frequent forest fires, overgrazing etc. are considered to be the main factors for the evolution of savanna biome). There are clear-cut evidences to demonstrate that the Savanna regions of India have certainly originated and developed because of deforestation of the original forests by man because Indian Savanna areas are found within and around deciduous forest covers. Unlike other main Savanna areas of the world Indian Savanna areas are dominated by shrubs instead of grasses. It may be concluded that the Savanna biome is the outcome of a set of complex factors such as characteristic features of climate, geomorphic history, natural fires, the evolution of grazing animals and their consequent impact on natural original vegetation and above all the presence of man and his various activities.

Climate

The Savanna climate is characterized by distinct wet and dry seasons, mean high temperature throughout the year and abundant insolation. Mean annual rainfall ranges between 250-500 mm on the desert fringes of the Savanna and 1300-2000 mm on its border with the equatorial climate. Temperature does not fall below 20°C in any month of the year. There are three seasons on the basis of the combinations of temperature and humidity (though on an average there are only two seasons as referred to in the beginning but the dry season is further divided into warm dry season and cold dry season on the basis of temperature) viz. (i) **cold dry season** is characterized by high day temperature ranging between 26°C-32°C, but relatively low temperature during nights, usually 21°C; (ii) **warm dry season** is characterized by almost vertical sun's rays, high temperature ranging between 32°C-38°C due to abundant insolation, and (iii) **warm wet season** receives between 80 to 90 percent of the total annual rainfall.

It may be pointed out that there is much pronounced variation in the spatial distribution of mean annual rainfall in the different parts of the Savanna biome of the world mainly because of two major factors viz. (i) distance from the equator, and (ii) the nature of topographic features. For example the Savanna region of Brazil, locally called as **Cerrado,** having the average absolute relief of 1300m AMSL, records mean annual temperature and mean annual rainfall of 20°C-26°C and 750mm-2000mm respectively. The **Llanos** of Columbia is characterized by mean annual rainfall of 2000mm-4000mm (near Andes mountain) and mean annual temperature of 22°C and the maximum temperature of 32°C. The Indian Savanna is characterized by highest temperature (being 45°C-48°C in May and June) and lowest temperature (being 5°C or even less during the month of January) of all the savanna regions of the world and mean annual rainfall well below 1500 mm, 80 to 90 percent of which is received during a brief period of 3 months (15th June to 15th September).

Vegetation Community

Though the general characteristics of typical Savanna vegetation are trees and grasses but the Savanna biome is, no doubt, dominated by grasses. The Savanna vegetation community has developed layered structure wherein three distinct layers have clearly developed.

(1) **Ground layer** is dominated by various types of grasses and herbaceous plants. The grasses, the most dominant vegetative member of the Savanna biome, are generally coarse, stiff and hard and of course perennial having the height of 80 cm but very long grasses reach upto 350 cm (3.5m) in height. The African elephant grass attains the enormous height of 500 cm (5m). The leaves of these grasses are almost flat which are shed during dry season but they are regenerated during wet season. The Savanna grasses are usually tufted in structure and form. It may be pointed out that not all the grounds are continuously covered by Savanna grasses, rather there are frequent open patches which are devoid of grasses. The root systems of the Savanna grasses consist of lateral dense network of fine branches which penetrate upto the depth of 2.5m in the soil cover. The important genera of the Savanna grasses are Hyparrhenia (elephant grass), Panicum, Pennisetum, Andropogon and African species Imperata cylindrica. The grasses bear deserted look during dry warm summer season but they become lush green again during humid summer season.

(2) **Middle layer** consists of shrubs and very small woody plants.

(3) **Top (canopy) layer** is formed by trees of various sorts. The general characteristics of trees depend on the availability of water and moisture and therefore there is a great taxonomic variety of Savanna trees which are usually 6-12m in height. The Savanna trees have developed various unique characteristics to cope with the dry conditions of this biome. For example, there are a few species of trees

which have developed such mechanisms which help them to reduce evapotraspiration from their leaves during warm dry season and enable them to remain green even during dry season of deficient water supply. On the other hand, there are such tree species which cannot withstand dry conditions and therefore they shed their leaves and bear the characteristics of deciduous trees. The roots of the Savanna trees have also developed according to the environmental conditions as they are very large which can penetrate into the soil and ground up to the depths from 5m to 20m so that they can obtain water from groundwater even during dry season when the groundwater table falls considerably. The smaller plants and many herbaceous plants have special kinds of root systems characterized by root tubers and swellings so that they may preserve water which may be used by the plants during dry season, because the roots of these plants seldom reach the depth of more than 20 cm in the soils and the coarse soils up to this depth become dry during dry season.

The trees form flattened crown or canopy but they are very sparsely distributed. Several branches come out from the stems which are mixed up with the middle layer. Some of the Savanna trees are fire resistant (**pyrotic**) as they have thick bark and thick bud-scales. The Savanna biome is characterized by the monotony of tree species as there are very few tree species per unit area as compared to the tropical rainforest and tropical monsoon deciduous forest biomes. For example, baobab is the only significant tree from Tanzania to Senegal and the Savannas of Ivory Coast and Sudan are dominated by palm trees. The important tree species are Isoberlinia, the baobab and dom palm in Africna Savannas; species of eucalyptus such as E. Marginata and E. Calophylla in Australia; pine trees in Honduras etc.

The net primary productivity ranges from one place to another place depending on the nature of tree densities. The mean net primary productivity of the Savanna biome is 900 dry grams per square metre per year but there is great spatial variation in the productivity as it ranges from 1500 dry grams per square metre per year in the **closed savanna** (dominated by trees and shrubs) to a minimum of 200 dry grams per square metre per year in the desert scrub Savanna.

On the basis of the proportion of trees and grassland and the structure of the vegetation the Savanna biome may be divided into the following four types (P.A. Furley and W.W. Newey, 1983) :

(1) **Woodland Savanna** is dominated by trees and shrubs which form dense upper canopy. This Savanna is, thus, also called as '**closed savanna**'. Inspite of comparatively closed upper tree canopy of the topmost layer, enough sunlight reaches the ground surface to support ground cover of herbaceous plants. There is more or less general absence of **epiphytes** but some climbers having their roots in the ground are present.

(2) **Tree Savanna** represents relatively open vegetation cover in terms of trees, and shrubs which are sparsely distributed. The ground cover is dominated by grasses. No tree canopy is developed.

(3) **Shrub Savanna** is represented by treeless vegetation which is dominated by grasses at the ground layer and shrubs at the second layer. In fact, shrub Savanna is two layered vegetation where the topmost layer is formed of shrubs and the ground cover consists of grasses.

(4) **Grass Savanna** is characterized by general absence of trees and shrubs and over dominance of dense grasses. The grasses cover is not continuous, rather it is separated by intervening patches of grassless areas.

The frequent fires, both natural and anthropogenic (intentional annual burning of grasses by man), are common features of all the aforesaid Savanna biomes. Though many organic materials are destroyed due to annual burning of grasses by man, regular fires in Savanna grasslands are very important ecological processes because these favour regeneration of grasses every year, mineralisation of leaf litter and regulation of fauna. 'Thus fire appears to be a normal part of the Savanna biome and one of the major factors in its nature......Savanna (is) a delicate balance of the outcome of climate, soils, vegetation, animals and fire, with fire as the key agent whereby men have created the biome; as it now stands this biome in Africa cannot be regarded as climatic climax but as a product of human activity' (I.G. Simmons, 1982).

No doubt frequent burning of grasses by man has been responsible for the evolution of a few fire-resistant species of trees and grasses such as Imperata spp (a type of grass).

Animal Community

It may be pointed out that animal communities of different Savanna areas of the continents show a wide range of species diversity because of the fact that (i) different Savanna areas have developed differently in different environmental conditions during various stages of evolution, and (ii) the degree of human interference has greatly varied in different Savanna regions. The availability of food during different seasons depends on the environmental conditions. Since there is maximum growth and development of vegetation during wet summer season and almost barren ground during dry summer season and hence there is abundance of food during wet season but there is marked scarcity of food during dry season. This seasonal regime of the availability of animal food has largely affected animal community in the Savanna biome. Secondly, hunting of animals by man has also adversely affected them. Inspite of these limiting factors the Savannas are capable of supporting a very diverse fauna.

The African Savanna accounts for the largest number and the greatest variety of grazing vertebrate mammals in the world. For example, the East African Savanna carries 40 species of very large herbivourous mammals such as African buffalo, zebra, giraffe, elephants, many types of antelopes, hippopotamus etc. of which even 16 species graze together in the same habitat. On the other hand, the South American and Australian Savannas do not have large number of grazing mammals similar to the African Savanna but great variety of birds like those of the African Savanna is invariably found. The Australian Savanna is dominated by **marsupials** (typical mammals of South American and Australian origin having pouch in their bodies to keep and feed their offsprings). There are at least 50 species of kangaroo in the Australian Savanna which greatly vary in size ranging from very large red kangaroo (1.5m tall) to very small species of wallaby (only 30 cm in height). The large grazing mammals of the South American Savannas include deer and guanaco. Besides, toucans, parrots, nightjars, kingfishers, doves, finches, parakeets, wood peckers are also found in large number in the South American Savannas.

It may be pointed out that relatively less dense cover of vegetation in the Savanna biome provides maximum mobility to the animals and thus the Savanna grasslands have been responsible for the origin and evolution of great number of large mammals (like elephant, giraffe, zebra, ganda, hippopotamus, gazells, antelopes etc.) and birds such as courses, bustards, game birds, ostrich, and several non-flying birds like emu.

There is complete correlation and correspondence between the structure and seasonal regime of the Savanna vegetation and invertebrate animals. The invertebrate animals include insects (such as flies-Diptera, locusts, grasshoppers, termites-Isopetra, ants and arthropods (like spiders, scorpions etc.) which are found profusely in the various parts of the Savanna regions. The density of oligochaete worms, spiders and insects in the Guinea Savanna of tall grasses of the western Africa is 50,000 to 60,000 per 300 square metres of area during dry season but the density of these organisms increases to 1,00,000 during wet season because of regeneration of dense cover of green grasses. The rainy season is characterized by the dominance of smaller animals (such as springtails, ants, earwigs, cockroaches, small crickets, carabid beetles etc.) whereas the larger invertebrates dominate during dry season like locusts, grasshoppers, mantids and crickets.

It may be pointed out that inspite of large number and great variety of animals of invertebrate and vertebrate categories (ranging from micro-organism-like insects to very large bodied animals like giraffe and elephants) there is no competition for food among the animals in the Savanna biome because of the fact that the animals of this biome have developed typical feeding habits and mechanisms according to the characteristics of the vegetations. For example, giraffe uses the top layers of the trees and shrubs through his exceptionally long neck, zebra lives on the leaves of shrubs and the heads of tall grasses, wildbeasts graze the grasses of medium height whereas the gazelles (deer family) depend on short grasses. It appears that there is close correspondence between the vertical stratification of the vegetation community and feeding habits of the animals of the Savanna region. Thus the Savanna biome is characterized by the development of grazing succession which enables the animals of various species and sizes to live in the same habitat without having much competition among themselves for food.

There is also wide range of variation in the seasonal mobility of the ungulate animals (animals having hoofs) and thus the seasonal variability of the animal mobility has also discouraged competition among the animals for food. Based on seasonal characteristics of mobility, A.F. Lampray (1964) has divided the animals of the Savanna biome into the following 5 categories :

- Animals with little or no seasonal movement, e.g. giraffe, grant's gazelle, hartebeests etc.
- Animals having partial movement during dry season, e.g. impala.
- Animals having partial movement during wet season, e.g. worthog, dikdik, waterbuck, rhino etc.
- Animals migrating during dry season e.g. buffalo, zebra, wildbeest, eland, elephant etc.
- Animals used to passage migration, e.g. buffalo, zebra, elephant etc.

Ecological Productivity

The East African Savanna is the richest of all the other Savannas in terms of total animal population. 'Where a rich fauna still exists, as in East and Central Africa, it may achieve a yearlong vertebrate biomass of 100×10^5 kilogram per hectare live weight' (I.G. Simmons, 1982). The average **net primary productivity** (NPP) of the Savanna biome is 900 dry gram per square metre per year whereas the total net primary productivity of all the Savannas of the world is 13.5×10^9 tons per year. The termites are very significant animals of the Savanna biome because they help in decomposing the organic matter and in recycling the nutrients. According to an estimate (I.G. Simmons, 1982) the biomass of termites in Ivory Coast is 12 kg per hectare and these consume 30 kg of cellulose per hectare per year and rearrange several dozen tons of soils every year.

Human Interactions

The impact of man in the Savanna biome right from the evolution of human races in the various parts of the present-day Savannas to the present-day technologically advanced society has been so immence that the very nature and the characteristics of savanna grasslands are the outcome of the continued man's interferences with the original natural environmental conditions particularly natural vegetation and related micro-climates. The regular burning of vegetation generates lush green grasses during the wet season which support large number and variety of grazing animals but simultaneously this routine annual practice reduces the number of large animals feeding on the leaves of trees because frequent fires are not conducive for luxriant growth of trees.

The rapidly increasing human population for the last 50 years or so has put enoromous strain on the natural Savanna grasslands because a vast area of the original grasslands has been converted into agricultural fields to grow more food crops to feed the teeming millions. The rapid rate of expansion in the agricultural lands under the new scheme of **green revolution** has further been responsible for the shrinkage of natural Savanna grasslands. Further more, enormous increase in the number of domesticated animals has greatly damaged the grasslands. In nut shell, the impact of human activities has resulted in the shrinking of the areas of grasslands and reduction of natural vegetation which have caused shortage of food supply to the animals. All these have ultimately adversely affected the animals communities. Consequently, the number of animal species and their total population are gradually decreasing.

4. MEDITERRANEAN BIOME

Location and Extent

The Mediterranean biome is also called as **sclerophyl ecosystem or biome** because of the development of special features and characteristics in the dominant trees and shrubs to adapt to the typical environmental conditions of the Mediterranean climates (dry summer and wet winter). The Mediterranean biome has developed between 30^0-40^0 (some times upto 45^0) latitudes in both the hemispheres in the western parts of the continents. This biome includes the European lands bordering the Mediterranean Sea, central and southern California of the U.S.A., central Chile of south America, north-western coastal lands of Africa bordering the Mediterranean Sea and the far south-western part of South Africa and the coastal zones of western and southern Australia and the Asiatic coastal lands bordering the Mediterranean Sea (western Turkey, Syria, western Israel and Lebanon) (Fig. 12.7).

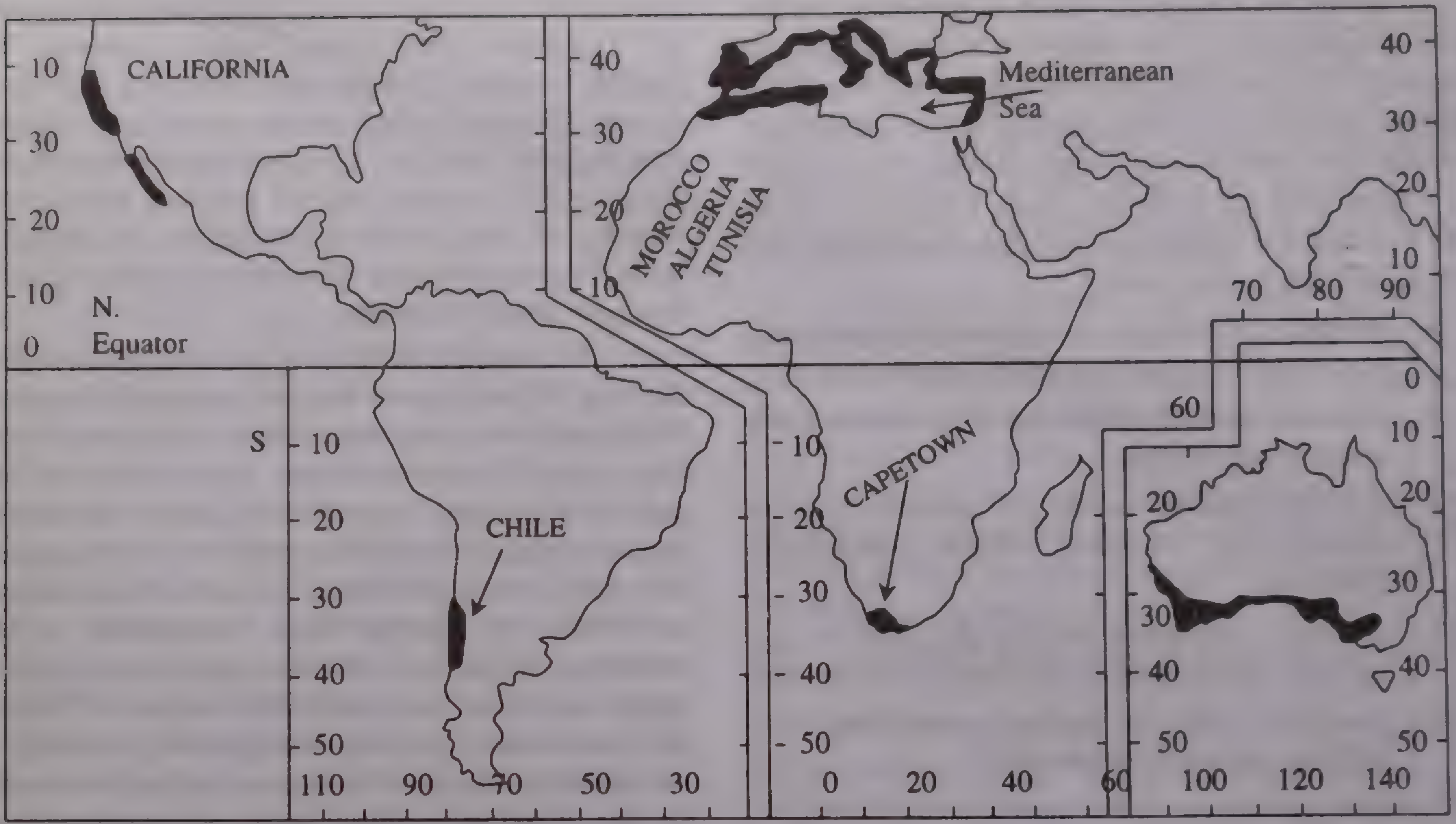


Fig. 12.7 : Distribution of Mediterranean Biome.

Climate

The Mediterranean climate has three typical characteristic features which give sclerophyll characteristics to the vegetation of this biome e.g. (i) Winters are cool but wet whereas summers are dry. Most of the annual rainfall is received during wet winter months; (ii) Summer season is warm and dry whereas winters are moderately cool, and (iii) There is sufficient sunlight throughout the year but summer is more sunny. These characteristic climatic features of the Mediterranean climate have developed because of the seasonal shifting of the pressure and wind belts due to northward and southward migration of the Sun.

The average temperature during cool winter season ranges between 5^{0}C and 10^{0}C whereas mean summer temperature varies from 20^{0}C to 27^{0}C and thus.the annual range of temperature becomes 15^{0}C to 17^{0}C or even more. Mean annual rainfall ranges between 370 mm and 650 mm, the most portion of which is received during winter season. The winter rainfall is received through the cyclonic storms associated with the westerlies. The summer season is almost dry. This seasonal regime of rainfall causes fluctuations in the soil-water and soil-moisture regime during winter and summer seasons. The amount of soil-water increases during winter season because of winter and spring rainfall which is responsible for maximum growth in the vegetation but dry summer season causes deficiency in the soil-water content because of loss of water and moisture due to increasesd evaporation and evapotranspiration because of substantial increase in temperature and of course due to general lack of precipitation during summer season. Thus the deficiency in soil-water content during dry summer season prevents vegetation growth.

Vegetation Community

Though the Mediterranean regions are widely scattered over different continents, there is more or less broad generalization in the overall structure and composition of the vegetation community of all the regions of the Mediterranean biome. The structure of the Mediterranean vegetations is such that they can withstand the aridity of summer season. Consequently, the leaves have developed sclerophyllous characteristics wherein they are stiff and hard and the stems have thick barks. The Mediterranean vegetation community consists of a variety of sclerophyll plant formation classes which range from Mediterranean mixed evergreen forests (in the coastal lands immediately bordering the seas and the oceans) to woodland, dwarf forest and scrubs. The vegetation community is dominated by trees and shrubs. The shrubs are differently named in the various parts of the Mediterranean biome on the basis of local names e.g. **maquis** or **garrigue** in southern Europe, **chaparral** in California, **fymbos** or **fymbosch** in South Africa and **mallee scrub** in Australia.

The plants of the Mediterranean biome have developed several morphological characteristics to withstand dry conditions. Such structure is called **xeromorphic structure** such as thickened suticles, grandular hairs, sunken stomata etc. The sclerophyllous structure of the plant leaves enables them to regulate the gaseous exchange according to the availability or scarcity of water during different seasons of the year. A few species of trees such as **mastic trees**, have the mechanism of adjusting themselves to the changing weather conditions during the year. For example, the mastic trees are able to close their stomata during dry summer season or even during winter drought so that they can reduce transpiration from their leaves to minimum and hence can conserve moisture. Some trees have developed smaller leaves (such as **chamise**) so that they allow minimum loss of moisture through transpiration. Some trees have thorny leaves (such as succulent cactus family).

The plants of the Mediterranean biome have also developed special types of root systems in accordance with the regional environmental conditions mainly the availability of moisture. For example, some plants have extensive root systems with strong tap root which extends even into the consolidated parent rocks (such as the roots of almond); some plants have such root systems which develop above the ground as well as quite deep inside the ground (such as the root of chamise); some plants have bulbous or tuber roots (such as the geophyte plants, e.g. different types of flowers like dehlia) etc.

There are some regional variations in the species composition and vertical structure of the vegetation community in the various parts of the Mediterranean biomes as given below :

(1) **European Mediterranean biome** is characterized by multi-layered structural pattern of the vegetation community wherein three distrinct layers (strata) have developed. The topmost first layer or the canopy layer is dominated by oak tree which is of two types e.g. (a) evergreen oak, and (ii) deciduous oak. There are several species of oak in the European Mediterranean biome. The sequence of trees changes with the increasing altitude e.g. the evergreen oaks are found at the lower height and with the increasing height the sequence of trees is formed by deciduous oaks, beech, fir and pine. The second or the middle layer is formed of shrubs which include the species like arbutus, pistacia, rhammus, ceratonia etc. These shrubs attain the height of 2m or even more which are clearly differentiated from the topmost layer of the dominant oak trees of 3 to 4m height. These shrubs provide valuable forages to the animals and valuable products to human beings like gums, resins, tannins, dyes etc. The continuous grazing, natural and anthropogenic frequent fires and felling of trees have largely transformed the shrub community called as **maquis** into **garrigue**. The garrigue shrubs have also been modified by continued human activities and transformed into **batha** (dwarf shrubs). The third or the ground layer consists of numerous herbaceous plants.

(2) **North American or Californian Mediterranean biome** is dominated by different species of oak trees and **chaparral** shrubs. The first or the topmost layer is formed by the canopy of oak trees reaching the height between 6m and 23m. The oak has short but thick stem and flattened crown. The second or middle layer is dominated by various shrubs locally called as **chaparrals.** The ground layer is dominated by herbaceous plants and grasses. Chaparrals generally become gregarious in the areas of less fertile and light soils. The chaparrals of California are the counterpart of the European **maquis.** The duarf shrubs (like **batha** of the European Mediterranean biome) locally called as **sage scrub** have developed in many parts of the Californian Mediterranean biome. The Mediterranean biome of Chile of South America has also developed vegetation quite similar to that of the Californian Mediterranean biome. The Californian chaparrals are called **mattoral** in Chile.

(3) **South African Mediterranean biome** is characterized by the dominance of small but attractive flowering plants of numerous varieties. These plants have been extensively migrated by deliberate actions of man to various garden's of numerous countries of the world. These garden flower plants include erica, ereesia, lobellia, kniphofia

species etc. The shrubs belong to sclerophyllous categories as these are characterized by hard, stiff and thick leaves. These sclerophyllous shrubs are locally called as **fymbos.** It may be pointed out that this region was originally covered by temperate forests before the arrival of Europeans in this area. The Europeans largely removed the original forests for the purpose of agriculture and thus there developed the secondary succession of vegetation which now has taken the form of present-day **fymbos.** The large-scale transformation of original habitats through forest clearance and mass hunting of animals by the Europeans resulted into the obliteration of several species of animals from the South African Mediterranean biome. For example, **quagga,** species of zebra, has now become totally extinct. Only a few species of antelope like duiker and steenbuck are found only in the dense cover of **fymbos.** Hyraxes, baboons, and leopard are found in small number only in the mountainous areas.

(4) **Australian Mediterranean biome** is dominated by the species of eucalyptus. Thus the topmost layer or the canopy layer is formed by about 100 species of evergreen eucalyptus trees with the height of 70 m or even more. The tallest species of eucalyptus is **karri.** It may be pointed out that the forms of vegetations change inland from the coastal areas and thus several zones of vegetations are found from north to south. The southernmost coastal land having maximum amount of annual rainfall is characterized by the dominance of eucalyptus forest which is replaced by **jarrah forest** in the north. Further northward the forest cover becomes thin and is finally replaced by grasslands. **Malle scrubs** have developed to the north and east of grasslands. There are numerous animals in the malle scrubs.

Ecological Productivity

The average **net primary productivity** (NPP) of the Mediterranean biome is about 700 dry gram per square metre per year whereas the total net primary production of all parts of the Mediterranean biome is 6×10^9 tons per year. The NPP of 700 dry gram per square metre per year generates a biomass of 6000 grams per square metre.

Animal Community

Like vegetation, there is also regional variation in the animal communities of the various parts of the Mediterranean biomes of the world. The Mediterranean biomes of California and Chile are characterized by more or less similar animal species. There are numerous animals in these two regions because of abundant supply of food from the good cover of various types of shrubs.

There are about 201 species of vertebrate animals in south California, of which about 75 percent are bird species. The large mammals of Californian and Chilean regions include mule deer (in California) and Chilean guanaco but the latter is no more a browsing animal rather it has changed its feeding habit and it has been transformed to grazing animals. The mammals are now dominated by ground squirrels, wood rats and mule deers. Many of the predator species like wolf and mountain lion, diversivores like grizzly bear have now become rare species because of increasing pressure of man on the Mediterranean vegetation. The other important animals include several species of rodents such as rabbits, the rabbit predators such as cyote, similar to Chilean fox, other predators such as lizards, snakes, and several types of raptorial birds like kites, falcons, hawks etc.

Most of the original native animals of the South African Mediterranean biome have now become either extinct or rare due to the destruction of their natural habitats through extensive forest clearance by the European settlers. For example, quagga, a type of zebra, which was an important species, now has become totally extinct whereas bontebok, a type of antelope, has now become a rare species and has been pushed to remote areas. Some animal species, which were very important before the arrival of Europeans in this area, have now occupied remote areas to escape from the hunters. These animals include some species of antelopes (which now live in the dense shrubs of high ground) like duiker and steenbuck; rodent like browsing small animals like hyraxes (which have now been pushed to mountainous areas); baboons and leopards (which also live, though in very small number, in the remote hilly and mountainous areas).

The Australian Mediterranean biome is chatacterized by numerous types of birds and animals. The marsupials include kangaroos mainly western grey kangaroo. There are numerous varieties of wallaby and mice. The typical birds of the shrub habitats and grasslands are honeyeaters, whistlers, wrens, robins, quail-thrushes etc.

Human Interactions

Man has directly (through his deliberate actions) and indirectly adversely affected the flora and fauna of the Mediterranean biomes. Fire, both natural and man-induced, is normally of annual occurrence in the Mediterranean biome. The natural forest fires occur through lightning whereas man burns the grasses to get luxuriant growth next season. There is a common practice to burn the vegetation each year or after two or three years after heavy grazing and browsing by sheep and goats. Similarly, vegetatoins are burnt in every part of the Mediterranean biomes. The recurrent burning of vegetation has certain positive ecological results e.g. (i) Most of the plant species of the Mediterranean biomes have become fire-resistant and are now well adapted to fires. In other words, the plants, after burning, bear luxuriant growth of new branches, shoots and leaves. For example, numerous stems come out from the burnt stumps of eucalyptus trees; (ii) Some seeds germinate more quickly and properly after fires; (iii) Burning of vegetation transforms the organic matter into ashes and thus facilitates the mineralisation of organic matter and ultimately makes the mineralised organic matter available to plant roots; (iv) Fire destroys poisonous compounds secreted by plant roots. If undestroyed, these poisonous compounds are very injurious to plant communities because these do not favour decomposition of leaf litters and prevent nitrogen fixation in the soils.

The burning of vegetation has certain negative results as well. For example, soil structure is changed by frequent fires and thus is subjected to accelerated rate of soil erosion during the rainstorms. Besides burning of vegetation, mass clearance of natural vegetation for agricultural and commercial purposes, overgrazing of grasslands and large-scale hunting of animals have led to elimination of certain animal species, accelrated rate of soil erosion, increase in the silt load of major rivers and alteration of original natural vegetation, habitats and micro-climates.

TEMPERATE GRASSLANDS BIOME

Location and Extent

Temperate grasslands are located in the interiors of the continents which come in the westerly wind belt but because of their more interior

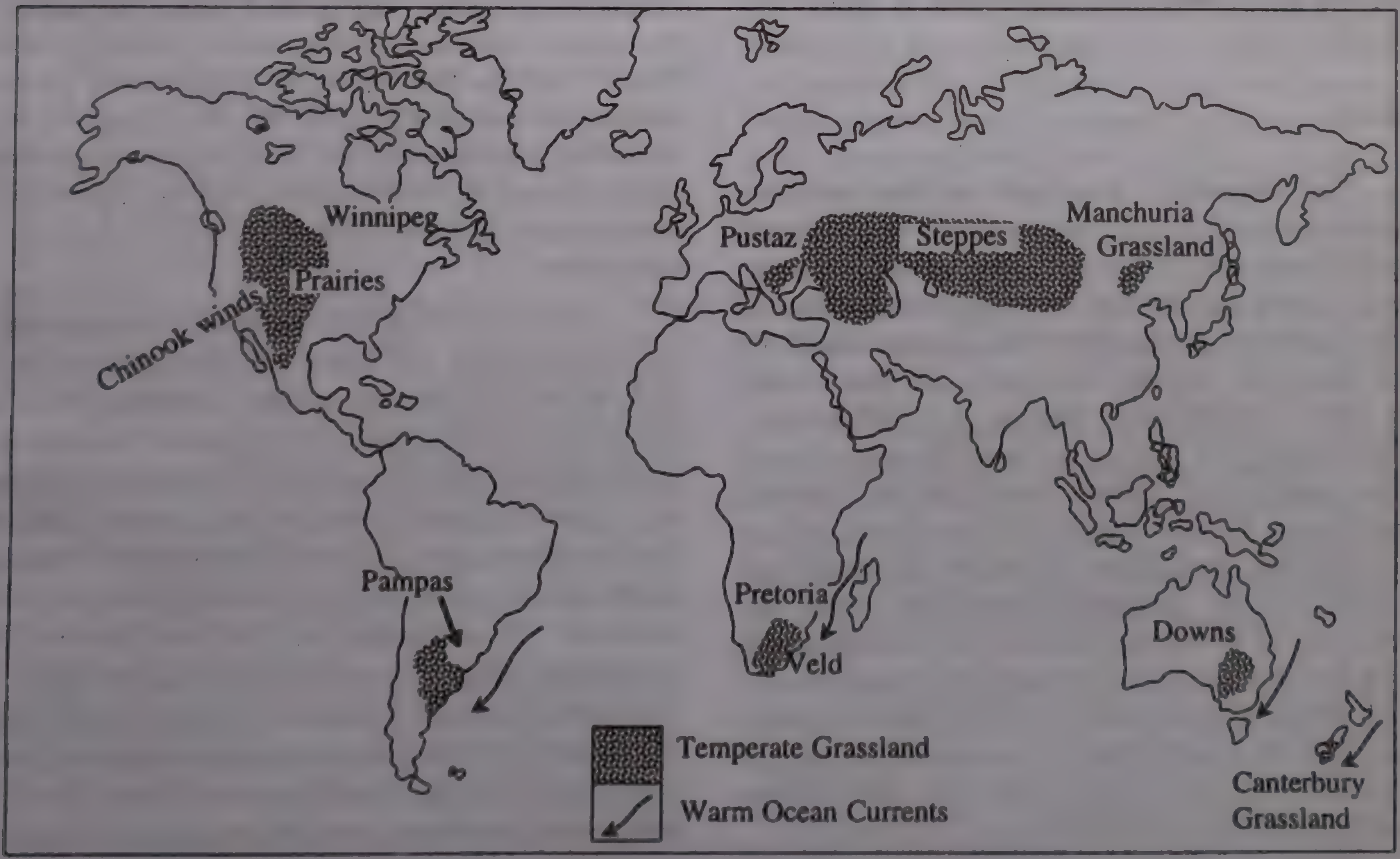


Fig. 12.8 : Distribution of temperate grassland biome.

locations they do not get sufficient rainfall and hence the grasslands are practically treeless. The temperate grasslands of the southern hemisphere are located along the south-eastern margins of the continents and therefore have more moderate climate than their counterparts of the northern hemisphere because of more marine influences as they are closer to the marine environments. The temperate grasslands of Eurasia, known as **steppes**, are most extensive as they extend for a distance of more than 3200 km from the shores of the Black Sea across the Great Russian Plain to the foothills of the Altai Mountains. Their continuity is broken at few places by the highlands. There are also some isolated patches of steppes e.g. in Hungary (known as (**pustaz**) and in the plains of Manchuria (Munchurian grassland). The temperate grasslands of North America (extending in the U.S.A. and Canada both) are locally known as **prairies** which extend from the foot-hills of the Rockies in the west to the temperate deciduous forest biome in the east. The temperate grasslands of the southern hemisphere include the **Pampas** of Argentina and Urugay of South America; **bush veld** and the **high veld** of South Africa; and **Downs** of the Murray-Darling basins of south eastern Australia and **Canterbury grasslands** of New Zealand. (fig. 12.8).

Climate

The temperate grasslands of the northern hemisphere are characterized by continental climate wherein extremes of summer and winter temperatures are well marked but the temperate grasslands of the southern hemisphere are characterized by more moderate climate. Summers are warm with over 20^0C temperature during July (Winnipeg, Canada) and 22^0C during January (Pretoria, South Africa, January is summer month in the southern hemisphere). Winter season becomes very cold in the northern hemisphere because of enormous distances of the temperate grasslands from the nearest sea as Winnipeg records-20^0C temperature during January. On the other hand, the steppe climate of the temperate grasslands of the southern hemisphere is never severe rather it is moderate because of the nearness of these areas to the sea. The average winter temperature ranges between 1^0C and 12^0C.

The steppe climate is characterized by high annual range of temperature. For example, Winnipeg (Canada) records mean annual range of temperature of 40^0C. Due to marine influences, the mean annual range of temperature in the southern hemisphere is much lower than the northern hemisphere as it is around 10^0C to 12^0C. The mean annual precipitation ranges between 250 mm-750 mm in different locations of the temperate grasslands. The winter precipitation in the northern hemisphere is usually received in the form of snowfall and most parts of the Eurasian steppe are snowcovered for several months during northern winters. Most of the annual rainfall is received during summer season.

Vegetation Community

Grasses are the most dominant members of the different regions of the temperate grasslands of both the hemispheres. The perennial grasses, mostly belonging to the family of **gramineae,** of this biome are considered to be the **climax community**. Besides, some herbaceous plants are also found in this biome but trees and shrubs are conspicuous by their general absence. There are two concepts of the evolution of temperate grasslands biome viz. (i) The temperate grasslands are the result of climatic conditions and pedogenic properties of these areas. The extreme continental climate and limited supply of water to the plants because of low rainfall are the main factors for the dominance of grasses and general absence of trees and bushes. (ii) The climatic origin of the temperate grasslands is not always acceptable because many scientists believe that these grasslands are the result of human activities mainly burning of vegetation.

This biome exhibits close relationships among vegetation types, soil types and climatic conditions and between plant and animal communities. The temperate grassland biome is unique in the sense that it has single-layered structure of vegetation community where the upper canopy of the grasses is formed by their leaves but for a short period the flowering stalks also join the canopy and add grandeur to the top-layer. The flowers do not have petals. The pollination of flowers and the dispersal of seeds are facilitated by wind. It may be pointed out that most of the areas of the temperate grasslands have been now cleared and are used for cereal crops. Thus the temperate grasslands have become now the granaries of the world and the heartland of the world dairy industry. Since there are some spatial variations in the general characteristics of the vegetations of the different parts of the temperate grasslands of the northern and the southern hemispheres, a brief separate description of vegetation characteristics of each region is necessary to understand the overall nature of the vegetation community of this biome.

(1) **European steppes** biome has the largest areal extent in Russia wherein it extends from eastern Europe to western Siberia and between temperate coniferous forest in the north and arid regions in the south-west. The Russian steppes are divided into two sub-types on the basis of vegetation e.g. (i) **forest steppe,** and (ii) **grass steppe.** These two combined together represent 12 percent of the total geographical area of the former Soviet Union. The forest steppe consists of alternate bands of woodland and open steppe. The European forest-steppe is represented by oak, limes, elms and maple while the Siberian part of forest steppe consists of birch, aspen and willow. The intervening bands of open steppes in the forest steppes are called **meadow steppes** which are characterized by the common genera of grasses of fescues (Festuca) and feather grasses (Stipa). The forest steppes receive mean annual precipitation between 500 mm-600 mm whereas the grass-steppes receive mean annual precipitation of 400 mm-500 mm.

The combinations of climate, vegetation and soil change from north to south in the Russian steppes. In the extreme northern part of the Russian steppes are found forest steppes. The soils of the woodland steppe or the forest steppe are degraded chernozem because the chernozem has been extensively leached out and transformed into grey forest soils. The grass steppes, further south of the forest steppe, is characterized by true chernozem soil. Further southward, the increasing aridity has been responsible for the transformation of true grass steppe into **semi-arid steppe** which is associated with chestnut soil. Further southward the climate becomes arid and steppe grasslands cease to exist. The following sequences of vegetation are found from north to south in the Russian steppe :

(i) **Forest steppes** consist of trees mainly oak, elms, limes, mapple, a few arboreal vegetation of Siberian steppe such as birch with mixture of aspen and willow. The soils have degraded chernozem. There are alternate bands of open steppes between the woodland bands.

(ii) **Meadow steppes** are open steppes between the woodland zones of the forest steppes as described above. The meadow steppes have developed in the areas of well developed deep chernozem soils. These are characterized by the species of turf-grasses (such as the species of Stipa and Fescue) and numerous flowering herbaceous plants (such as trifolium and several types of daisy).

(iii) **Grass steppes** are found over well developed deep chernozem soils and are dominated by grasses, wherein the tussock forming species of stipa are the most important members of the vegetation community. Besides, a few flowering xerophytic shrubby species of artemisia are also found in the southern marginal belt of the main grass steppes.

(iv) **Semi-arid xerophytic steppe** is found in the extreme southern and south-western parts of the Russian steppes where the xerophytic grasses (such as fescue and feather grass species) are also associated with chestnut soil and semiarid climatic conditions (mean annual precipitation ranging between 300 mm and 350 mm). A few species of xerophytic herbs (such as artemisia) and some ephemeral herbs are also found in this semiarid tract.

(2) **North American prairies** have developed in the U.S.A. and Canada between the foothills of the Rockies in the west and the temperate deciduous forest biome in the east. On the basis of decreasing trend of mean annual precipitation from east (1050 mm) to west (400 mm) and a gradient of falling net primary productivity (NPP) the North American Prairies, are devided into 3 sub-reginos viz. (i) tall grass prairie, (ii) short grass prairie and (iii) mixed grass prairie. It may be pointed out that there is a complete sequence of taller to shorter grasses from east to west.

(i) **Tall grass prairie** is found in the eastern part of the north American temperate grasslands (prairies) wherein the most dominant species of the tallest grass are bluestem and switch grasses which attain the height of 1.5 of 2.5m. There are a few patches of oak and hickory trees within the vast areas of tall grasses.

(ii) **Mixed prairie** has most extensive cover in the Great Plains of the U.S.A. This belt extends between the U.S.-Canada border in the north and Texas in the south. This prairie is characterized by the mixture of medium (0.6-1.2m in height) and short grasses such as little bluestem, needlegrass (Stipa spartea), June grass (Koeleria cristata) and the short and bunch grasses such as buffalo grass

(Buchloe dactyloider) and blue gramma (Bouteloua gracilis).

(iii) **Short grass prarie** is developed in the western part of the Great Plains and is dominated by the species of short grasses which seldom exceed the height of 60 cm.

(3) **South American Pampas** have their most extensive cover in Argentina where these account for about 15 percent of its total geographical area. The South American Pampas are comparatively more humid than the Eurasian Steppes and North American Prairies. The mean annual precipitation decreases from the east (coastal land, 900 mm) to west (450 mm). Thus the Pampas are divided into two sub-types e.g. (i) **humid pampas,** and (ii) **sub-humd pampas**. The humid pampa, developed in the eastern part of Argentina, is characterized by tall grasses whereas the increasing aridity westward results in the growth of short grasses in the western sub-humid pampa. The important grasses of the pampa include briza, bromus, panicum, paspalum, lolium etc. It may be pointed out that the grasses of the pampas have multilayered structure which is the result of the availability of moisture, soil and effects of grazing by the animals. Man has introduced lucerne plant of legume species which forms good forage for the animals. Major part of the pampas has been cleared of their original grasses and has been converted into agricultural farms mainly wheat fields.

(4) **African Veld** has developed on the high plateau land of varying heights (1500 m to 2000 m) in the south-eastern part of South Africa. The African Velds include the temperate grasslands of southern Transwaal and Orange Free State of South Africa and some parts of Lisotho. It may be pointed out that the South American Pampas are developed on flat lowland terrain whereas the South African Velds have developed over 1500-2000 m high plateau surface where the growth of plants is not possible because of uncertainty of rainfall, increasing aridity, severity of frosts during nights and high daily range of temperature during winter season. Thus the true **climax grasslands** of African Velds have developed. There are much variations in the composition and structure of grasses because of variations in the topographic characteristics, soils, altitudes and climatic conditions. Based on aforesaid considerations the South African Veld Biome is further divided into 3 sub types, e.g (i) themeda veld, (ii) alpine veld, and (iii) sour veld,

(i) **Themeda veld** has developed at the altitude ranging between 1500 m and 1700 m where mean annual precipitation of 650 mm to 750 mm is recorded. The most dominant grass species is red grass (Themeda triandra) which has developed on black turf soils. It may be pointed out that the original dominant red grasses of this biome have been transformed to less useful xerophytic forms because of continued pressure of overgrazing by man.

(ii) **Sour veld** represents those areas of Themeda veld which are dominated by relatively less important grasses such as aristida, eragrostis and hyparrhenia.

(iii) **Alpine veld** is found over relatively higher altitudes (2000-2500 m) of the Darkersberg Mountain where Themeda grasses are found mixed with Festuca and Bromus which are developed on black soils.

(5) **Australian Downs** have developed in the south-eastern parts of Australia and the northern part of Tasmania. This region is characterized by (i) relatively warmer winter season than the temperate grasslands of the northern hemisphere (Eurasian Steppes and North American Prairies), and (ii) mixture of grasses with eucalyptus trees. The grasslands gradually change from south (Australian coast) to north (interior land) in accordance with the decreasing trend of mean annual precipitation from south (1524 mm) to north (635 mm). Thus 3 distinct and different grasslands are found in the Australian Downs (temperate grasslands) e.g. (i) temperate tall grasslands, (ii) temperate short grasslands, and (iii) xerophytic grasslands.

(i) **Temperate tall grasslands** have developed in a region which extends from the eastern coastal lands of New South Wales to Victoria and eastern Tasmania. The dominant grasses are Poa tussock and Themeda Australia. The Themeda Australia is also called as kangaroo grass because it is very much palatable to kangaroos. Danthonia pallida dominates the areas with drier environmental conditions.

(ii) **Temperate short grasslands** have developed parallel to but north of the temperate tall grasslands as discussed above. The important grasses developed in this biome include short species of grasses such as Danthonia and Stipa genera of grasses.

(iii) **Xerophytic grasslands** are developed further northward such as the interior lands of New

South Wales and Queenlands which are characterized by semi-arid climatic conditions and the grasses, which have developed in this biome, are adapted to dry conditions. The important species of this biome are Aristida and Mulga (a shrub species).

(6) **Canterbury Grasslands of New Zealand :** The original temperate grasslands were developed in the eastern part of the southern island and the central part of the northern island of New Zealand wherein the tussock or bunch grasses were the dominant species but man has changed and transformed the original structure of the temperate grasslands within the last 100 years or so through his economic activities. At present there are two main types of grasses in the temperate grassland biome of New Zealand e.g. (i) short tussock grasses having the main species of Festuca and Poa, are 50 cm tall and yellow-brown in colour, and (ii) tall tussock grasses (main species being Chinomechloa) are found relatively over higher grounds.

Animal Community

The animal community of the temperate grassland biome is characterized by a unique property in that every grassland region of the southern and the northern hemispheres is dominated by a few species of large mammals. For example, buffalo and pronghorn antelope in the North American Prairies; wild horse and saiga antelope in the Eurasian Steppes; antelopes in the South African Velds and guanaco in the South American Pampas. Secondly, the large herbivorous animals of the temperate grasslands are endowed with sturdy bodies so that they are able to protect themselves to some extent from their predator enemies like wolf and coyote. Thirdly, the grazing mammals have developed migratory habits so that they may avoid overuse of their forage and thus can conserve their food resources. Inspite of the aforesaid and even more similarities in the animal communities of the different regions of the temperate grassland biome there are some regional variations as well.

(1) The most important animals of the **Eurasian steppes** are saiga antelopes of the western steppes and Mongolian gazelles of the eastern steppes and the rare species of wild horses of the ungulate category (animals having hoofs). Among the burrowing animals rodents are important species. These rodents and mole rats dig out long and circuitous tunnels in the soft-dry soils to store food and to protect them from severe cold. They remain indoor throughout the day (in side their tunnels) but come out of their tunnels during night to get food. Predator animals include wolves, eagles, large hawks etc. which depend on rodents for their food. Polecat is also an important species of smaller predator animals.

(2) The bisons and pronghorns dominated the animal community of the North American Prairies before the arrival of the European settlers, explorers and fur traders in this continent but now these animals are on the verge of extinction because of their indiscriminate mass hunting by the European immigrants. Similarly, there were numerous species of rodents in the American Prairies such as gophers and prairie dogs which used to live in long and narrow tunnels dug-out in the loose and dry soils to protect them from the predators during day-time but most of these rodents have been either eliminated or markedly reduced in number because of removal of grasses on a large-scale for agricultural development. A large number of predator species depending primarily on rodents such as hawks, eagles, rattlesnakes, foxes, wolves etc. have also been adversely affected by ever-expanding agriculture in the prairies. Thus the agricultural development of the north American Prairies has provided food to large number of human population on the one hand but this practice has disturbed the original natural ecosystem of the Prairie grassland and has created ecological imbalance on the other hand.

(3) The South American **pampas** have now become major wheat fields and the remaining grasslands are so open that herbivorous animals are provided little natural refuge and protection from predator animals. The pampa deer is important among many species of herbivorous grazing animals whereas rodents mainly viscacha and mara are important burrowing species of mammals which like the rodents of the North American Prairies live in long and circuitous tunnels dugout in the loose and dry soils. Rhea is very important flightless species of birds which resembles emu of the Australian Downs and ostrich of African Savanna. Inspite of its giant body size the rhea becomes successful to some extent in protecting him from his predators because his colour helps him to become invisible in the surroundings of the local vegetation and his height enables him to see and detect the

enemies (predators). The predator animals include manned wolf which depends on rodents, birds and even small reptiles. The pampas are enriched by many migratory seasonal birds such as herons, geese, ducks, etc.

(4) The animal life of the South African **Velds** has been largely affected and modified by human activities. The region was earlier enriched by large herds of game, antelopes, hyaenas, jackals, lions, leopards etc. (all belonging to carnivorous category) and zebra but now these animals are not seen in the Veldean grassland because large-scale hunting has either eliminated them or has forced them to seek refuge in other areas. Since most of the natural habitats of these animals have been converted into farmlands, the original animals have also been replaced by domesticated animals such as farm animals, cattle (for dairy purposes), sheep and goats. Some of the birds and most of rodents are still found in this biome because the birds having high degree of mobility easily escape from their most dangerous enemy (man) while the rodents hide them in the long and circuitous earthen tunnels. The important species of rodents are springhare and gerbil whereas important species of carnivorous group of burrowing animals include yellow mongoose.

(5) The Australian **Downs** are dominated by kangaroos which are of three types e.g. (i) red kangaroos, (ii) grey kangaroos, and (ii) wallaroos. The European rabbits introduced in this biome have so greatly multiplied within the last 100 years or so that they have now outnumbered other animals and have become dominant animal species of the Australian temperate grasslands. The introduction of sheep for commercial purposes has also altered the composition of animal community in this grassland biome. Emu is the typical flightless bird species of this region.

(6) The New Zealandean grassland biome is characterized by almost general absence of herbaceous mammals because of the fact that this island probably has always been isolated from the other landmasses and therefore no migration of animals from other areas into New Zeland could be possible. Previously this biome was inhabited by giant flightless birds, the moas, but now these have disappeared because of their large-scale hunting by man.

Ecological Productivity

The average net primary productivity of the temperate grassland biome is 600 dry grams per square metre per year whereas the total Net Primary Production of all the regions of this biome spread in the northern and the southern hemispheres is 5.4×10^9 tons per year. The average biomass of these grasslands is about 1600 grams per square metre. It may be pointed out that the temperate grasses have well developed network of root systems. The roots may penetrate upto 2m in the ground whereas the shoots of the grasses are only 0.6 to 1.2m above the ground. It is thus obvious that the root systems of the temperate grasslands have more biomass (2000 grams per square metre) than the biomass of grass standing above the ground (1600 grams per square metre). The long and dense mesh of root systems of short and bunch grasses such as blue grama and buffalo gasses account for 50-55 percent of their total biomass.

Human Interactions

The climatic conditions, resultant soils, native and transformed regional vegetations, animal communities and of course man produced a unique interactive temperate grasslands biome ecosystem but the dominant activities of man and their widespread impacts on the total transformation of this biome/ecosystem have altogether changed the very nature of this biome/ecosystem. 'So virgin grasslands are rare since most of them have been altered by pastoralism of domesticated animals, replaced by agricultural ecosystems, or converted into a different species composition through the use of biocides (weed and/or pest killres) or mechanical processes such as brush removal, seeding with leguminous species or simply through the invasion of new (including exotic) species following utilization by man' (I.G. Simmons, 1982).

No other natural ecosystem or biome tells the story of the impact of human activities better than the temperate grassland biomes of the world. Majority of the original grasslands have now been converted into agricultural farmlands which have now become famous 'granaries of the world'. Wheat, corn and diary farming now occupy most of the areas of the North American Pairies (of the U.S.A. and Canada); wheat fields have replaced most of the Steppes of Kazakhastan and of northern China; South American Pampas are now extensively farmed for wheat and the semi-arid temperate grasslands have been converted into great sheep and cattle ranges of the world.

The wide-spread agricultural development in the temperate grassland biomes at the cost of natural and original stands of rich grasses of numerous varieties have led to the emergence of several ecological and environmental problems.

- The conversion of natural grasslands of this biome resulted into the obliteration of natural habitats of the animals of numerous species. Thus the disappearance of natural habitats or their overall transformation has caused disappearance and extinction of several animals species. For example, bisons and pronghorns, once the dominant animal species of the North American Prairies, are now facing imminent extinction; many rodents of the temperate grasslands have now become endangered species because of the destruction of their natural hideouts of tunnels dug-out in the loose and dry soils through large-scale ploughing by tractors; many of the animal species such as game, antelopes, zebras, lions, leopards and hyaenas have disappeared from several temperate grasslands etc.
- Large-scale hunting of animals has resulted into phenomenal decrease of the populations of some animals, migration of some animals to other areas and disappearance and extinction of some animals. For example, many species of animals such as game, antelope, zebra, lions, leopards, hyaenas etc. have disappeared from the African Velds because of mass hunting of animals by the European immigrants.
- The introduction of new species of exotic animals has altogether changed the composition of native vegetation. For example, the introduction of sheep by the European settlers in Australia has changed the composition of vegetation community which was originally suited to the native marsupial animals. The introduction of European rabbits into Australia by the European immigrants has resulted into such a phenomenal growth in their populations that they have become menace to both the natural vegetation community and man. Predator foxes have been introduced in this region to control the ever-increasing population of rabbits but this has not produced any fruitful result.
- The introduction of new species of exotic plants into many parts of the temperate grasslands has either suppressed the native natural vegetation or has eliminated many plant species. For example, the introduction of a few species of leguminous plants such as clover and grasses such as bromus, hardeum and perennial ryegrass by European immigrants into Australian temperate grasslands has suppressed several species of native perennial grasses.
- Extensive cultivation of the semi-arid prairie regions of the Great Plains of the U.S.A. has resulted into enormous deflation of dry, loose and friable soils by wind which (deflation of soil particles) generates dust storms during the period of drought which cause great damage to crops and human property in the Mississippi plains. Due to greater frequency of intense dust storms the areas of the semi-arid parts of the western Kanasas, Texas and Oklahoma are called as **'dust bowl'**.
- The large-scale removal of vegetation for agricultural purposes has resulted in the loosening of the soil cover because of the destruction of dense network of root systems of grasses. This change in the soil cover has resulted into accelerated rate of soil erosion and therefore loss of otherwise rich and fertile soils.

6. BOREAL FOREST (TAIGA) BIOME

Location and Extent

The boreal forest biome, also called as **temperate coniferous forest biome** or **taiga biome,** represents the taiga or the Siberian type of climate and includes the areas of sub-arctic regions of North America (extending from Alaska of the U.S.A. across Canada to the Hudson Bay in the east) and Eurasia (from the Scandinavian Peninsula across the Russian Siberia to the Bering Sea). Besides, there are small patches of natural coniferous forests at higher altitudes in Germany, Poland, Switzerland, Austria and other parts of Europe and on the high Rocky Mountains of North America. In fact, the taiga biome is located between the tundra biome in the north, and the temperate grassland biome (Eurasian Steppes and North American Prairies) in the south. The taiga biome is conspicuous by its total absence in the southern hemisphere because of narrowing trend of the continents towards the south pole (fig. 12.9).

Climate

The taiga or the Siberian climate of the boreal forest or the temperate coniferous forest biome is characterized by continental climate marked by bitterly cold winter of long duration and cool brief summer season. Spring and autumn are merely brief transitional periods between summer and cold seasons. The 10°C isotherm of the warmest month forms the northern boundary of this biome. The temperatures of winter months are always below freezing point. The temperatures of the coldest and the warmest months (Moscow) are-12°C and 20°C respectively and thus the annual range of temperature becomes 32°C. Verkhoyansk of the Siberia records the lowest temperature of -68°C. Soil water is frozen for 5 to 7 months of winter season in continuation. The mean annual precipitation ranging between 370 mm and 600 mm is received mostly in the form of snow which accumulates throughout winter and is released as surface water due to thawing because of increase in temperature during summer season. It may be pointed out that the precipitation is more or less uniformly distributed throughout the year whether in liquid form as rainfall or in solid form as snowfall. Thus there is no month without some form of moisture.

The following are the main characteristic features of the taiga or the Siberian climate of the temperate coniferous forest biome :

- Bitterly cold long winter season (temperature is below zero degree centigrade at least for 6 months).
- Heavy snowfall during winter season.
- Formation of permafrost (permanently frozen) ground because of freezing of ground moisture due to very low temperature as referred to above.
- Cool summer of short duration having precipitation in liquid form-rainfall and melting of snow cover.
- Growing period of vegetation ranging from 50 days a year (along the northern boundary) to 100 days a year (along the southern boundary).
- High range of variability in the spatial distribution of annual precipitation (i.e. annual precipitation varies between 350 mm and 2000 mm in both the forms-snowfall and rainfall in different parts of this biome).
- Extreme annual variation of temperature (ranging between 25°C during summer months and -40°C during winter months).

Vegetation Community

The coniferous trees are the most dominant member of the taiga or the boreal forest biome. The coniferous trees are well adapted to the extreme environmental conditions of the Siberian type of climate of this biome. These trees form dense cover of forests which are the richest sources of softwood in the world. These trees are used for various purposes e.g. for building construction, furniture, matches, paper and pulp, rayon and other branches of chemical industry. There are four major genera of evergreen coniferous trees e.g. (i) pine (Pinus-white pine, red pine, Scots pine, jack pine, lodgepole pine); (ii) fir (Abies-doughlas fir, balsam fir etc.); (iii) spruce (Picea), and (iv) larch (Larix). Besides, a few species of temperate deciduous hardwood trees have also developed in this biome mainly in those areas which have been cleared by man through felling of original temperate coniferous trees. Thus the temperate deciduous trees represent the **secondary succession** of vegetation. These temperate hardwood and broad-leaved deciduous trees include the genera of alder (Almus), birch (Betula) and poplar (Populus). The following are the characteristic features of the temperate coniferous forests :

- The gymnosperm conifers are the most important member of the vegetation community of the temperate coniferous or the boreal forest biome.
- Coniferous forests are of moderate density. Unlike the equatorial forests characterized by luxuriant growth, dense plant cover, varying heights of trees etc., the temperate coniferous forests are more uniform and grow straight and tall.
- Most of the coniferous trees are evergreen as there is no annual replacement of new leaves because trees do not shed their leaves enmass as is the case of deciduous trees.
- The coniferous trees assume conical shape with tapering top-end so that snow may not

accumulate on the branches and leaves of these trees rather this shape facilitates the snow to slide down the trees.

- Leaves of the coniferous trees are small, thick, leathery and needle-shaped so that they may control excessive transpiration during winter season.
- Coniferous forests are characterized by very little undergrowth because the poor and leached podzolized soils having higher acid content do not favour much vegetative growth at the ground surface below the forest cover of tall conifers.
- Seeds of the coniferous trees are closed in the outer shells of conical shape.
- Due to spatial variations in the climatic conditions, topography and soils there is marked spatial variation in the size, composition and structure, branching patterns and species of the coniferous trees.
- Usually the conferous trees are tall and their average height ranges between 12m and 21m but some trees of the mountainous location attain the height of even 100m.

On the basis of regional variation in the overall characteristics of vegetation communities the boreal forest or the temperate coniferous forest biomes are divided into two sub-types viz. (1) North American coniferous forest biome, and (2) Eurasian coniferous forest biome.

(1) **North American Temperate Forest Biome** : has developed in Alaska of the USA and Canada. Thus the lowland temperate coniferous forest is found between the Arctic treeline (tree line is that northward (in the case of mountains, the upward) limit beyond which no growth of tree is possible) or the southern boundary of the treeless tundra biome in the north (determined by 1^0C isotherm of the wermest month) and the northern limit of the temperate deciduous hardwood and broadleaved forests in the south. There is a well developed gradation of vegetation community from north to south in accordance with the combinations of climate, topography and soils as given below :

(i) The extreme northern zone of the boreal or temperate coniferous forest biome is characterized by extreme climatic conditions and is known as **forest tundra** which represents the mixture of tundra and boreal vegetations. This zone is dominated by the clumps of larch and spruce trees.

(ii) Woodland subzone has developed just to the south of the northern forest tundra and is characterized by open covers of coniferous trees such as black spruce and white spruce. The open character of the woodland sub-zone or the open forest of coniferous trees (trees are widely spaced resulting into moderate density) has been responsible for the development of rich ground cover of shrubs, mosses and lichens.

(iii) Further south of the woodland sub-zone has developed the true coniferous forest with dense tree cover. The most dominant tree species of this southernmost zone of the temperate coniferous forest are white spruce, black spruce and balsam fir.

It may be pointed out that there is very close relationship between tree types and soil types. For example, the areas of fertile and well drained soils are associated with rich stands of white spruce and balsam fir; sandy soils support jack pines and shallow depressions have given birth to marshes and swamps, the margins of which are enriched by the clumps of black spruce.

It may be further pointed out that there are few localities of mixed forests in Canada mainly in its south-eastern parts where the mixed forest formations of evergreen coniferous trees and deciduous broad-leaved trees (e.g. hemlock,. sugar maple, American elm and eastern while pine) have developed because of local climatic conditions.

(2) **Eurasion Temperate Coniferous Forest Biome :** extends from the northern Scotland (of U.K.) in the west, through Scandinavia, European Russia and Siberia to the Bering Sea in the east. This biome has the largest areal extent in a wide belt having north-south width of 1600km in the former Soviet Union. Like the North American temperate coniferous forest biome three sub-zones of forest tundra, woodland sub-zone or, open forest and true coniferous forest (as referred to above) from north to south have also developed in this biome. The uneven distribution of glacial soils of Pleistocene Ice Age have largely affected the types and distribution of vegetation in this biome. Spruce trees have developed in the areas of clay and loam soils while sandy soils have favoured the growth of pine trees. The intermediate zones between the forests mainly the margins of depressions and lakes have supported alders, birch and willow trees. Fir, spruce, pine and larch trees dominate in the western Siberia whereas temperate deciduous trees are the main species in the middle Siberia characterized by very severe winters.

The temperate coniferous or boreal forest biome of North America and Eurasia could not develop vertical stratifications like the biomes of the tropical and sub-tropical regions because of climatic conditions and resultant soil formation. The dense and closed coniferous forests have minimum undergrowth of ground cover whereas open forests have some undergrowth of a few types of shrubs and some herbaceous plants. The uniformity of the temperate coniferous forests facilitates easy exploitation of timber wood.

Animal Community

On the basis of functions and feeding habits the animals of the taiga biome/ecosystem are divided into two major categories viz. (i) **sap-sucking species** (those animals which suck liquid saps from the branches and stems of trees, such as aphids), and (ii) **grazing** and **burrowing species** (those animals which graze grasses and eat new stalks of trees). The feeding mechanisms of these animals have adversely affected the vegetation communities in a variety of ways as fallows :

- The flow of fluids in different parts of a tree is greatly hampered because of sucking of saps by some animals from trees. This (lack of saps in trees) results in the defoliation of plants (shedding of leaves) and thus decrease in the number of leaves decreases photosynthesis and overall total food production by plants.
- The growth of branches and leaves is hampered and reduced due to consumption of stalks of trees by herbivorous animals.
- Some animals eat fruit and flowers of plants and thus by doing so they reduce the reproductive potentials of plants.
- Some plants are eliminated and some are suppressed due to various feeding mechanisms and habits of animals.

V.E. Shelford (1963) has divided the animals of taiga biome into 3 major groups on the basis of effects of animals on the biome viz. (i) domiant animals, (ii) influent animals, and (iii) minor influent animals.

The **dominant animals** affect the biome to such an extent that the whole composition and the very nature of the biome/ecosystem mainly the vegetation community and in turn the other animals are transformed. These dominant animals include large herbivorous animals such as moose who consume the leaves, small branches and new stalks of plants and harden the soils through their frequent movements. The **influent animals** include vertebrate carnivorous animals including man. It may be mentioned that man has now appeared with new technology the most powerful destroyer of forests and hence he should be included in the category of the **dominant animals** because he has destroyed most of the forest cover not only in this biome but in all the biomes of the world within last one hundred years or so. **The minor influent animals** include mostly invertebrate carnivorous animals and parasites. Numerous species of insects are also included in the **dominant category** of animals because they damage the plants by eating their leaves and new stalks, by defoliating the plants, by eating away the barks and roots of the plants, by making holes in the branches and stems of trees etc. Such insects include larch sawfly, pine sawfly, spruce budworms, etc.

Caribou and moose are important herbivourous animals of the boreal forest or taiga forest biome. These animals are necessary components of the taiga biome because they have a variety of feeding habits and therefore these help in the maintenance of ecological balance of this biome.

The important predator carnivorous animals include blackfly which sucks blood from the bodies of mammals and birds. The dominant predator carnivorous animals include timber wolf, lynx whereas bears and wolverines are important species of scavengers. The minor influent animals include mammals and birds such as spruce groups (North America), caperaillies (Eurasian organism feeding on needles of coniferous trees), red squirrels (feeding on seeds), crossbil etc. The minor influent predator animals include pine marten (which eat squirrels), owls and hawks (which eat small birds and mouse like rodents) etc.

This boreal or taiga biome is characterized by seasonal migration of some animals. During severe cold season some animals migrate southward into temperate deciduous forest biome and even further southward into grasslands and during summer a few animals migrate northward into tundra biome. There is very close relationship between climate and body structure of the animals. In other words, the animals have developed such body structures that they can withstand the severity of cold season. Most of the animals are endowed with thick skin, long and dense haris and luxuriant furs. Such animals are called fur animals such as mink, marten and beaver. This thick fur coating covering the animal bodies externally protects the animals from severe cold. As one goes northward, the size of animal increases so that they can withstand the severity of cold. There is seasonal problem of food supply of the animals with changing season. There is acute shortage of food for the animals during winter season because the soils are frozen, ground surface is covered with thick layer of ice and snow and smaller plants are hidden in the snow cover. In order to avoid starvation due to acute food shortage during winter season a few species of animals go for long hibernation.

In other words, the hibernating animals go to underground abode and become inactive and wait for favourable summer season. A few rodents take some food from the small plants which are under thick cover of snow. Some animals such as beavers store food for severe winter season.

Ecological Productivity

The average net primary productivity of the boreal forest or the taiga biome is 800 dry grams per square metre per year whereas the total primary net production of all the boreal biomes of the world is 9.6 × 10^9 tons per year.

Human Interactions

The temperate coniferous forest biome provides the largest amount of soft wood of the world and therefore man has encroached upon taiga forests for their commercial requirements. The secondary succession of temperate deciduous forests has developed in those areas which have been transformed by man through clearance of the original stands of temperate evergreen coniferous forests. The clearance of forests for agricultural purposes has not proved successful because the spodosols developed beneath the forest cover is not fertile and therefore cannot yield good crops without heavy ose of chemical fertilizers. Similarly, the podzol oils of the Siberian taiga are also not much suited to gricultural crops because of their poor qualities. W.J. Beal (1889) has aptly remarked about the status of North American spodosols. 'It would be impossile to profitably grow any forage, grain, fruit or egetable crop in this sandy soil without the use of rtilizer'. Thus the initial clearance of woodland of ub-arctic climate mainly in North America for gricultural purposes by the European settlers was ain abandoned and returned back to the forests ecause of failure of crops. This practice resulted into the development of secondary succession of temperate mixed forest of coniferous trees and deciduous broad leaved trees.

7. TUNDRA BIOME

Location and Extent

Tundra is a Finnish word which means barren land. Thus tundra region having least vegetation and polar or arctic climate is found in North America and Eurasia between the southern limit of the permanent ice caps in the north and the northern limit of the temperate coniferous forests of taiga climate in the south. Thus tundra biome includes parts of Alaska, extreme northern parts of Canada, the coastal strip of Greenland, and the arctic seaboard regions of European Russia and northern Siberia. Besides, tundra biome has also developed over arctic islands. Vegetations rapidly change to the north of tree line because of the increasing severity of climate. Thus based on variations in the general characteristics of vegetations in the arctic tundra (tundra biome is divided in two sub-divisions e.g. Arctic Tundra Biome and Alpine Tundra Biome where the latter is found over high mountains of tropical to temperate areas), three zones are recognized from south to north viz. (i) low arctic tundra, (ii) middle arctic tundra, and (iii) high arctic tundra. It may be pointed out that high, middle and low are not indicative of altitudes rather these indicate latitudes (figs. 12.9 and 12.10)

Low arctic tundra is the southern most zone of Arctic Tundra which includes most of northern Canada, northern Alaska, southern parts of Canadian Islands (e.g. southern parts of Banks, Victoria and south-eastern part of Baffin islands), southern coastal lands of Greenland and Siberian Peninsula. **High arctic tundra** includes the islands located to the north of Canadian archipilago (e.g. Queen Elizabeth island groups). This zone is characterized by sparse vegetations such as mosses, lichens and hardy herbs (such as avens and saxifrages). **Middle arctic tundra** is found between high tundra in the north and low tundra in the south.

Climate

The tundra or the polar climate is characterized by general absence of insolation and sunlight and

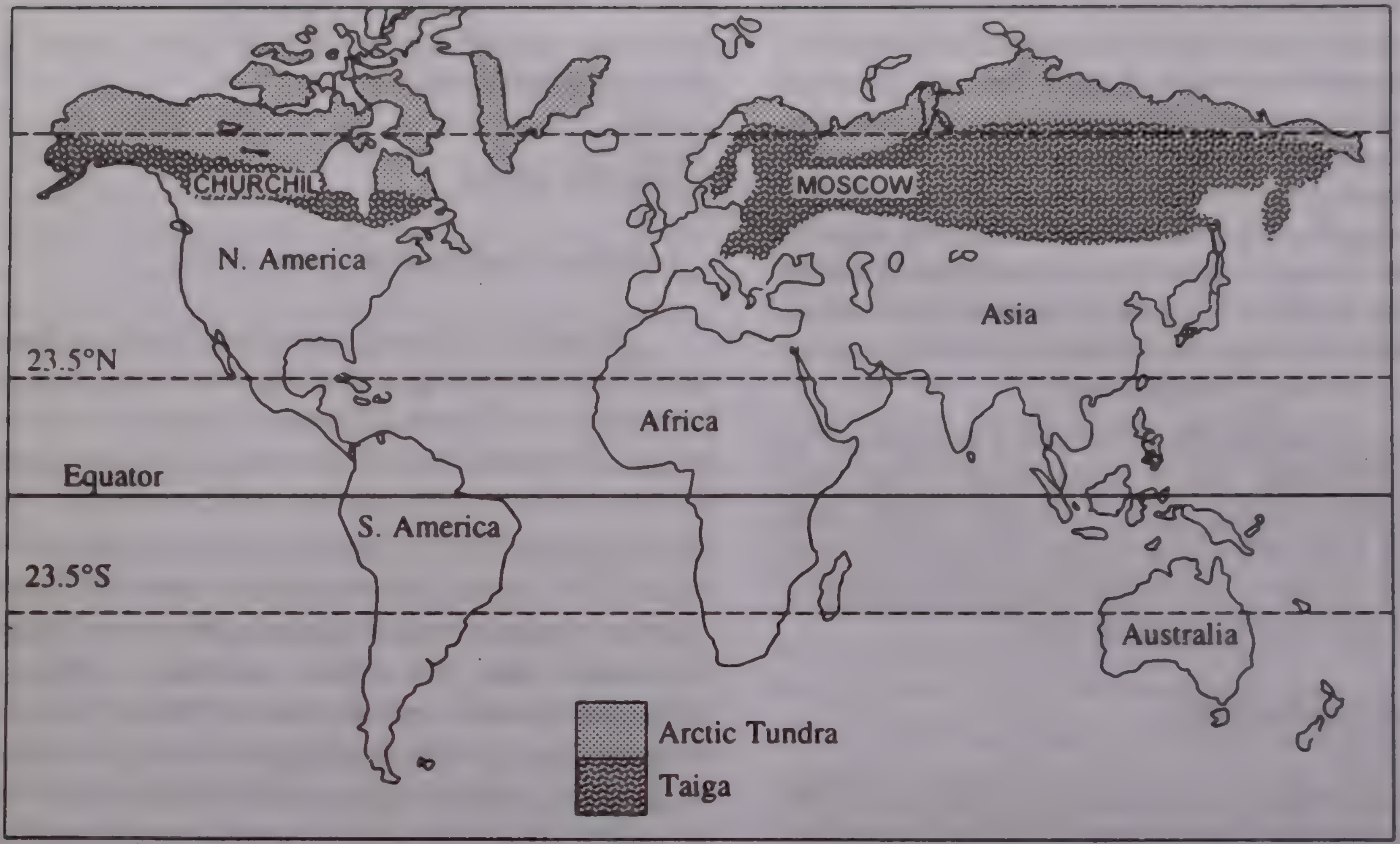

CHURCHILL
MOSCOW
N. America
Asia
23.5°N
Africa
Equator
S. America
23.5°S
Australia
Arctic Tundra
Taiga

Fig. 12.9 : Spatial distribution of taiga biome or temperate coniferous forest biome and Arctic tundra biome.

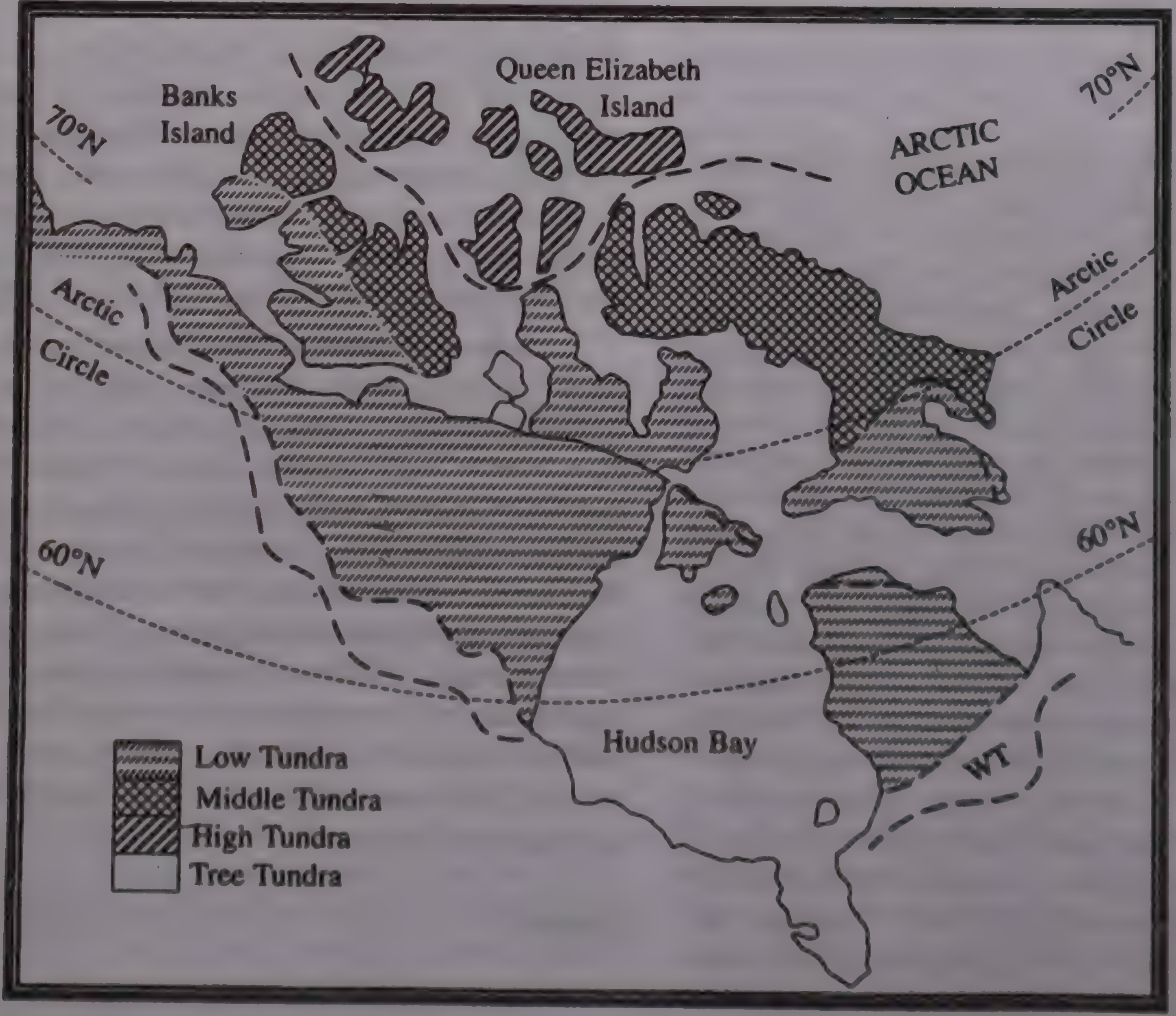

Banks Island
Queen Elizabeth Island
70°N
70°N
ARCTIC OCEAN
Arctic Circle
Arctic Circle
60°N
60°N
Hudson Bay
WT
Low Tundra
Middle Tundra
High Tundra
Tree Tundra

Fig. 12.10 : Divisions of Arctic Tundra of Canada.

very low temperature throughout the year. This severe climatic condition does not favour much vegetative growth and hence most of the Tundra remains a barren land. There is total lack of trees. The ground surface is covered with snow at least for 7 to 8 months each year. Temperature is generally below freezing point. The region is swept by speedy cold powdery storms known as blizzards. Growing season is less than 50 days in a year. The ground is permanently frozen (permafrost). Even soil is also perennially frozen. Mean annual precipitation, mostly in the form of snowfall, is below 400 mm. Winters are long and very severe whereas summers are short, moderately cool but pleasant.

Vegetation Community

There is perfect relationship between vegetation and the condition of moisture in the soils. The characteristic **lithosols** of the tundra biome (a well drained soil) support only lichens and mosses. Arctic gray soils favour the growth of dwarf herbaceous plants and bog soils maintain sedges and mosses. Only 3 percent species of the total world species of plants could develop in the tundra biome because of the severity of cold and the absence of minimum amount of insolation and sunlight. The vegetations of the tundra biome are **cryophytes** i.e. such vegetations are well adapted to severe cold conditions as they have developed such unique features which enable them to withstand extreme cold conditions.

According to N. Pollumin (1959) there are 66 families of cryophytes in arctic tundra biome. The number of plant species and plant population decreases northward with increasing severity of cold. Most of the plants are tufted in form and range in height between 5 cm and 8cm. These plants have the tendency of sticking to the ground surface because the temperature of the ground surface is relatively higher than the temperature of the overlying air. The herbs are developed mainly in those areas where heaps of ice and snow protect the plants from gusty icy winds. Such herbaceous plants include willow (Salix herbacea and Salix arctica). The stems and leaves of these herbaceous plants are very close to the ground surface (hardly a few centimetres above the ground surface). Though the growth rate of these herbaceous plants is exceedingly slow but their survival period is unbelievably very long (between 150 to 300 years).

The evergreen flowering plants develop on the ground like cushions mostly during short cool summers. These flowering herbaceous plants include moss campion (Silence acaulis). Some plants assume the shape of rosette wherein the leaves radiate from a point and leafless stalk bearing flower grows upward. Saxfragus nivalis is the typical species of rosette plants. Some plants are endowed with the typical features of fleshy leaves, thick cuticle and external covers of hairs (epidermal hairs) around their stems and branches. Some plants grow on the ground like tussocks while other groups of plants grow horizontally on the ground surface like mats or compact turf (such as Dryas octopetala). It may be pointed out that the period available for the growth of tundra plants is of only 50 days during cool summer season, during which all the stages of the life-cycle of a plant are completed e.g. growth of plant tissues, flowering, pollination, ripening of seeds, dispersal of seeds and establishment of seedlings etc.

Animal Community

The animals of arctic tundra biome are grouped into two categories viz. (i) **resident animals,** and (ii) **migrant animals**. Most of the animals leave Arctic Tundra and migrate southward during winter season to escape severe cold because only those animals stay at home during severe winter season which have such typical body structures which enable them to withstand the severity of cold. Thus the resident animals of relatively larger size have thick and dense insulating coat of fur or feathers around their bodies. Such epidermic insulating cover of fur or feathers works as blanket and keep the animals warm during severe winters. The American musk ox is a typical example of such animals. This bulky herbivourous animal living in the Arctic Tundra of Alaska, northern Canada and Greenland is endowed with epidermic coat of dense and soft wool around his body and an outer cover of thick and long hairs which are so long that they touch the ground. This thick coat protects the musk ox from cold and moisture because this thick coat works as insulator and is impervious for both, cold and moisture. Musk ox gets rid off this heavy coat during summer season to adjust with relatively warmer environment. Thus after shedding thick hairy and wooly coat the musk ox presents a ragged appearance. The animal is again endowed with this coat during the next winter. The

Arctic fox has double coats of fur around its body and thus is able to withstand very severe cold. It may be pointed out that the fur coat of the Arctic fox enables to bear as much low temperature as -50^{0}C and hence the animal is active even during severe winter season and is able to catch its prey such as lemmings and hares. The **resident birds** have feathers (such as ptarmigan) which protect them from severe cold. In fact, these feathers work as insulators. The smaller birds protect them from severe cold by shivering or by fluffing their feathers.

Some **resident animals** of the Arctic tundra biome change their colour during different seasons of the year. For example, ptarmigan (a kind of bird) changes the colour of its feathers thrice a year. The arctic foxes and stoat, prominent predator animals having fur coat, are brown in colour during summer season but become white in colour during winter season. Some animals such as wolves and caribou have such hairless feet which act as insulator and do not allow the heat of their bodies to escape. Some smaller animals such as rodents, lemmings, shrews, voles etc. live in burrows and tunnels during winter season to protect them from severe cold and hungry predator animals.

The second category of animals of the arctic tundra biome consists of **migratary animals** which start migrating with the beginning of winter season to warmer areas in the south and return back to their native places during coming spring season. The animals move away from their native places during every winter season because they are not equipped with suitable devices which may enable them to protect themselves from the severity of cold as is the case with the **resident animals** as referred to above. The birds, such as waterfowl, ducks, swans, geese etc., are the first to leave their native places with the arrival of autumn and are also first to come back to their original places in the spring or early summer. Some birds establish sexual contact before they return to their native places during summer season. Some birds return to the same nests which they left at the time of their migration during winter season. Since the summer season is of very short duration and many functions and duties like nesting, pairing or courtship (sexual contact between the pair of male and female birds), laying of eggs, hatching and rearing of offsprings are to be completed within this short period. The most of the birds are not used to have sexual contacts for long duration.

Some birds cover very long distances during the period of their migration. For example, the Arctic tern is the most important migratory bird, as it breeds during summer season in the Arctic tundra and leaves its native place with the beginning of winter season and reaches as far south as Antarctica in the southern hemisphere which is characterized by summer season. It is obvious that the Arctic tern is benefitted from two summer seasons in a single year. Mosquitoes, midges and blacky are important species of insects which emerge in huge and dense swarms in pools, ponds, lakes, bogs and swamps during summer season. Tundra birds feed and rear their offsprings on huge populations of insects, moluscs and worms which also emerge in huge swarms during summer season in pools, ponds, rivers, lakes, swamps and soils.

Raindeer and caribou are important animals of the category of large migratory animals. These mammals spend winter season in temperate coniferous forest biome or taiga biome located to the south of their native tundra biome and establish sexual contact. It may be pointed out that the female raindeer and caribou conceive through winter mating (sexual intercourse between male and female animals) during their winter migration to temperate coniferous forest but they deliver their offsprings in tundra regions during summer season when they migrate from temperate coniferous forests to tundra biome. Thus raindeers and caribous cover distances of hundreds of kilometers each year between summer and winter seasons of the same year. Some times mother raindeer and caribou deliver young ones in the transit and such newly born youngones perish in the way because they are unable to undertake arduous long journey. These animals again move southward in herds as the arrival of winter season is heralded.

This annual rhythm of migration of animals from tundras to southerly temperate coniferous forest regions during winter season and from the latter to the former during summer season continues without any interruption. It is significant to note that this seasonal migration of tundra animals is motivated by the availability and non-availability of food which is itself created by varying weather conditions of the region. The migrating herds of raindeer and caribou are attacked by wolves, and several weak, lame and ill animals and many youngones are killed and eaten away by predators. These animals are also attacked by great swarms of numerous mosquitoes and many bloodsucking insects during their summer stay in tundra region. These animals have no better alternative to escape from the attack of aforesaid insects than to take temporary refuge in ponds, lakes or streams whichever is nearer to their localities.

Ecological Productivity

Primary productivity in tundra biome is exceedingly low because of (i) minimum sunlight and insolation, (ii) absence or scarcity of nutrients (such as nitrogen and phosphorous) in the soils, (iii) poorly developed soils, (iv) scarcity of moisture in the soils, (v) permanently frozen ground (permafrost), (vi) very short growing period (about 50 days) etc. According to V.D. Alexandrova (1970) the mean regional primary productivity decreases from low Arctic Tundra (228 dry grams per square metre per year) to high Arctic Tundra (142 dry grams per square metre per year) whereas the lowest primary productivity of 12 dry grams per square metre per year is found in the polar desert areas. The net primary productivity (NPP) of the tundra biome is 140 dry grams per square metre per year whereas the total net primary production of all parts of the tundra biome is 1.1×10^9 tons per year. It may be pointed out that because of severity of climate and resultant poor vegetation, dry areas produce little litter but wet litter accumulates to form peat, and there is very slow and thus low nutrient release to vegetation. It is thus clear that the scarcity of food makes the tundra animals migratory.

Human Interactions

Man is closely associated with the biota of the tundra biome because even his very existence depends upon animals of both terrestrial and aquatic habitats. About 50 years ago the Eskimos of Greenland, northern Canada and Alaska; Lapps of northern Finland and Scandinavia; Samoyeds of Siberia; Yakuts of Leena basin and Koryaks and Chuckchi of north-eastern Asia spent complete nomadic life depending on their food derived from fish, seals, walruses, polar bears and other animals and on other commodities derived from caribou (the relative of Eurasian raindeer is called caribou in North American Tundra), raindeer and various fur animals. Thus the earlier nomadic tundra man inflicted a great damage to tundra animals through his hunting activities. But now the situation has changed as many of the people of the tundra biome are leading a permanent or semi-nomadic life. The Eskimos have established permanent settlements and have formed villages in the coastal areas of tundra regions and have domesticated caribou and fur animals. Many of Eskimo children have got modern education in the schools. They have adapted to new technologies. For example, deadly rifles have replaced the traditional and out-dated harpoons. Thus the modern Eskimos equipped with modern technologies are now in a position to damage the tundra ecosystem in the same way as is done by already technologically advanced man in other biomes. The Samoyeds and other tribes of the Eurasian Tundra have also adapted new way of life. Some of them are leading permanently settled life. They rear raindeers and fur animals and even grow food crops mainly wheat in the Siberian Tundra while some tribes still wander with their herds of raindeer across the Eurasian Tundra in search of pastures.

8. MARINE BIOMES

Main Characteristic Features

Marine biomes account for about two third of the total areas of all the biomes of the globe as sea water covers about 71 percent of the total geographical area of the world. The marine biomes have certain such typical characteristics (which are generally not possessed by terrestrial biomes) which affect the biological communities of the marine biomes as follows :

(i) The marine biomes provide a wide range of habitats for the marine plants and animals as the marine organisms can live in the shallow seawater, deep sea water and even at the deepest bottoms; they can live in coldest water near the polar zones but the terrestrial organisms cannot live beyond certain height and near the poles except a few species of penguins and other animals.

(ii) The sea water is characterized by more or less uniformity in the distribution of temperature and therefore marine organisms have not to adapt to extreme temperature conditions. Various forms of sea movements such as sea waves, tidal waves, oceanic currents, upwelling and subsidence (vertical movements of waters) and horizontal movement of surface water help in even horizontal and vertical distribution of temperature.

(iii) Sea water contains all the nutrients in solution form which are easily taken by sea organisms (plants).

(iv) The life-form and food chains and food webs in the marine biome depend on the availability of sunlight, water, carbon dioxide, oxygen etc. All of these elements are mostly confined to the upper zone of sea water and therefore most plant life is also confined to 200 m-thick zone of upper sea water because sunlight decreases with increasing depths and it practically becomes absent beyond the depth of 200 m from the water surface. This upper zone is called **photic zone** which is full of primary producer green plants called as phytoplanktons because these plants prepare their food through the process of photosynthesis with the help of sunlight and zooplanktons which are primary consumer herbivorous heterotrophic animals depending on phytoplanktons for their food.

(v) Since sunlight becomes totally absent at greater depths in the seas and the oceans and hence photosynthesis is not possible at greater depths, consequently the organisms depend on detritus (marine sediments) and are called deterivores.

(vi) Sea water provides maximum mobility to the marine organisms. Nutrients are circulated more quickly and efficiently and marine organisms are more rapidly dispersed than the terrestrial organisms. This is the reason that the distributions of marine plants and animals are more widespread and cosmopolitan than the distributions of terrestrial organisms.

(vii) Sinking of cold water from the water surface transports oxygenated waters to the sea bottoms which make animal life possible even in the deep oceanic trenches whereas animal life is not possible beyond a critical limit over high mountains because of lack of oxygen at much higher altitude.

Types of Marine Biomes

Different types of habitats are formed in the oceanic environment on the basis of various combinations of sunlight, availability of nutrients, carbon dioxide and oxygen and thermal conditions of sea water. These various habitats house different types of marine organisms (both, plants and animals). Based on salient environmental conditions of the marine environment, marine biomes are classified into two types e.g. (i) pelagic biome, and (ii) benthic biome.

Pelagic biome is further sub-divided into two types on the basis of depths and plantlife e.g. (i) neretic pelagic biome includes continental shelves with average depth of 200 m, and (ii) open sea pelagic biome.

On the basis of the availability of sunlight marine biomes are divided into two major divisions e.g. (i) euphotic or aphotic biome, and (ii) photic biome.

The following is the detailed classification of marine biomes :

(1) **Pelagic biome**
  (a) photic or upper pelagic biome
  (b) aphotic pelagic biome
    (i) mesopelagic zone
    (ii) bathypelagic zone
    (iii) abyssal pelagic zone
(2) **Benthic biome**
  (a) littoral zone biome
  (between high and low tide water)
  (b) sub-littoral zone biome
  (c) deep sea benthic zone biome
  (from 200 m to more than 6000 m depth)
    (i) archibenthal zone
    (between 200-1000 m depth)
    (ii) abyssal benthic zone
    (between 1000-6000 m depth)
    (iii) hadal zone
    (between 6000-7000 m depth)

Based on temperature and nutrients of oceanic water marine biomes are classified into the following types :

1. **Warm water continental shelves biome**
   (surface temperature over 20^{0}C, it represents photic zone and richest biome in terms of large variety of organisms living in the warm waters of continental shelves)
2. **Cold water continental shelves biome**
   (surface temperature usually less than 20^{0}C)
3. **Oceanic biome with upwelling nutrients**
   (sufficient nutrients are brought by upwelling of water)
4. **Cold open sea biome**
   (less number and variety of sea organisms due to poor supply of nutrients)
5. **Warm open sea biome**
   (upper 200 m is fully illuminated throughout the year but there is general lack of nutrients and hence less population of marine organisms)

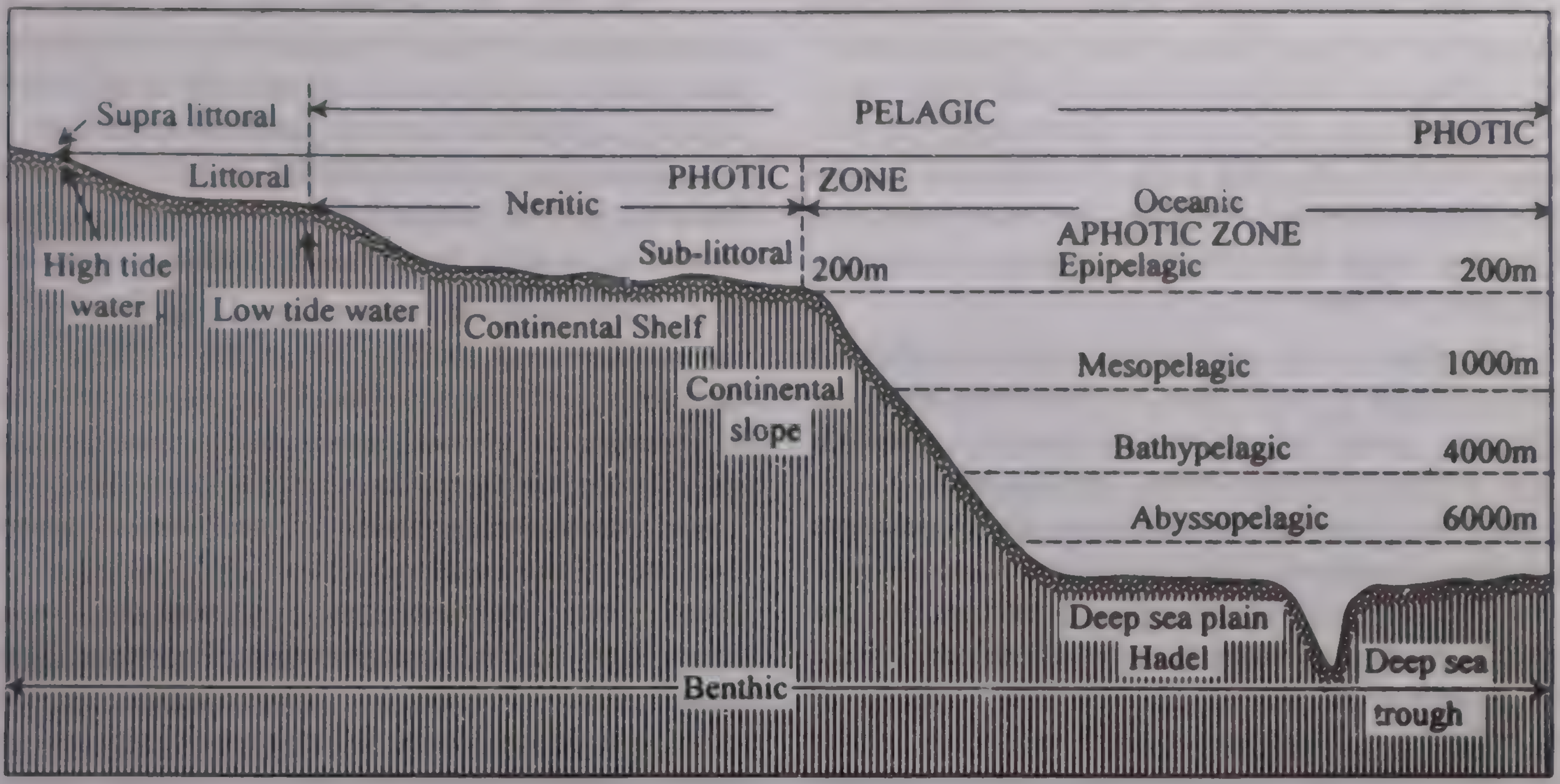

Supra littoral
PELAGIC
PHOTIC
Littoral
PHOTIC
ZONE
Neritic
Oceanic
APHOTIC ZONE
Sub-littoral
200m
Epipelagic
200m
High tide water
Low tide water
Continental Shelf
Mesopelagic
1000m
Continental slope
Bathypelagic
4000m
Abyssopelagic
6000m
Deep sea plain
Hadel
Deep sea trough
Benthic

Fig. 12.11 : Types of Marine biomes based on J.W. Headgepeth (1957).

MARINE BIOLOGICAL COMMUNITIES

Marine organisms including both plants and animals are divided into 3 categories on the basis of their habitats.

(1) **Planktons** are floating and drifting plants and animals of the euphotic zone of the seas and the oceans. Planktons are further divided into two sub-categories viz. (i) phytoplanktons (plant planktons) and (ii) zooplanktons (animal planktons).

(2) **Nektons** include large, strong and powerful floating and swimming marine animals mainly fishes. These marine animals move in all the zones of the oceanic environments.

(3) **Benthos** include those marine plants (non-photosynthetic or non-phototrophs) and animals which live at the bottoms of the seas and the oceans.

1. PLANTKTON COMMUNITY

Planktons include the groups of buoyant and floating marine plants and animals which live in the euphotic zone or epipelagic zone extending from sea water surface to the depth of 200 m. The plant planktons are called **phytoplanktons** because these are the primary producer green plants which manufacture their own food through the process of photosynthesis with the help of sunlight whereas the animal planktons are called **zooplanktons** which depend on phytoplanktons for their food. Phytoplanktons are microscopic in size but are very important members of marine organisms because all the animals of the marine ecosystem depend on these primary producer autotrophic microscopic green plants for their survival and existence. These phytoplanktons represent trophic level one of the marine food chains and food webs.

(1) Phytoplanktons

Phytoplanktons including diatoms and dinoflagellates produce most of the organic carbon in the seas and the oceans and most of the oxygen of the atmosphere. Goldenbrown algae and flagellated green algae are the other important members of phytoplanktons. Though phytoplanktons are microscopic in size but these have enormous reproductive ability as they are multiplied several times within a short period of time but these are also consumed by marine animals with the same speed as they are reproduced. It is obvious that the marine ecosystem is therefore more efficient and is maintained in equilibrium state because of balance between reproduction of phytoplanktons and their simultaneous consumption by marine animals.

Algae and diatoms are most important members of the phytoplankton community. These are microscopic buoyant and freely floating green plants at the water surface. Algae and diatoms are mostly produced and developed in the cold water biome but these are widely distributed by the oceanic currents in other parts of different marine biomes. The reproduction of diatoms is so rapid that these cover large areas of sea surface within very short period of time.

Flagellate is the second important sea plant of the micro-algae group. Most of the flagellates are autotrophic plant but a few of them depend on organic matter for their food. **Dinoflagellate** is the most important species of flagellates. **Gonyaulax** and **gymnodium** genera of flagellates are characterized by reproduction explosion which results in the development of enormous mass of these red-brown plants within short period of time. The swarms of these redbrown plants are called **red tides** which grow mostly in the tropical warm marine biome. **Cocolithophores** are the important members of the group of minor phytoplanktons. Though these grow mostly in the tropical marine biomes but some times they grow in large swarms in the North Sea.

Plant planktons/phytoplanktons also include numerous types of bacteria which are found in both cold and warm marine ecosystems but they mostly grow in the littoral biomes and the photic zones of the seas and the oceans because these bacterial plants depend on organic matter for their food and the organic materials are abundantly found in the littoral biomes and in the photic/euphotic zones.

(2) Zooplanktons

Zooplanktons or animal planktons include various life-forms of marine animals. The size of these marine animals ranges from a fraction of a millimetre to several metres. These zooplanktons are divided into 3 types e.g. (i) herbivorous zooplanktons, (ii) carnivorous zooplanktons, and (iii) deterivorous zooplanktons. It is important to note that this community is of key importance as its herbivorous forms (herbivorous animals of zooplankton community) are essential in the conversion of vegetable matter into animal protein; it is the fundamental bridge between the microscopic pastures of the sea (great swarms of plant planktons spread over larger area of the sea surface) and the largest marine animals' (P.A. Furley and W.W. Newey, 1983) because zooplanktons eat phytoplanktons and carnivorous marine animals feed on zooplanktons.

It may be pointed out that most of the zooplanktons remain permanently as zooplanktons but some zooplanktons spend only a part of their life-cycle in the form of planktons such as eggs, larvae and immature and undeveloped forms as these become **nektons** (such as fishes) and **benthos** (such as crabs) soon after they assume mature forms.

The **copepod** belonging to the group of small crustaceans and feeding on phytoplanktons is very important zooplankton which produces protein and is found in large number in many oceanic biomes. Thousands of copepods of a single species are found even in one cubic metre of sea water. About 67 percent of the total weight of zooplanktons of the North Sea is accounted for by copepods. Copepods have high rate of reproduction. For example, one single pair of Calanus finmarchicus species of copepods produces its three generations in a single year. Copepods are easy prey to several species of fishes such as herring, sprat, piechard etc.

Euphausiid is another important species of herbivorous zooplankton. These animals grow in large swarms in the Antarctic environment and become food of the large baleen whales. It is believed that these euphausiids may become important source of animal proteins for human food in coming future.

Arrow worm is an important carnivorous zooplankton but it is also eaten by herring and other fishes. These worms become large swarms in the shallow waters of the Atlantic Ocean off the coast of North-West Europe. Foraminifera and radiolaria are important protozoans which are abundantly found in the warm water biome.

Pleuston and **neuston** are also very important groups of zooplanktons. Pleuston is a very unique and typial marine zooplankton in the sense that its body is partly in the air above the water surface and partly in the water. Siphonophores (having floating bladder and long tentacles), salps and comb jellies are other important species of the pleuston group of zooplankton. Neuston group of animals includes those microscopic zooplanktons which live in large number in one millimetre-thick thin film of surface sea water becuase this thin layer contains rich nutrients, numerous bacteria and other microscopic organisms.

2. NEKTON COMMUNITY

Nekton community of sea organimss primarily consists of swimming animals of various depths of the seas and the oceans. Most of the animals of the nekton group are vertebrates. The most important and omnipresent component of the nekton group of animals is formed by numerous species of fishes. These are found in all types of marine biomes and in all oceanic depths. The marine fishes are divided into two groups viz. (i) pelagic fishes, and (ii) demarsal fishes.

The pelagic group of fishes such as herrings or anchovy live in the upper zone of the seas and the oceans whereas the demarsal group of fishes such as plaice, cod, haddock etc. live in great depths mainly on the bottoms of the seas and the oceans. Squids are the fast swimming invertebrate animals of the nekton group. Smaller squids move in groups and are thus easily trapped by fishermen because of their slow speed of movment but the larger squids generally escape from the trawler because of their sheer fast speed. The squids are carnivores but they are themselves the food of large fishes like sperm whales.

The swimmer marine mammals of nekton community are divided into two groups e.g. (i) Those marine mammals which live in water as well as on the land such as **seals**. Such animals get their food from the marine biome but breed on the lands. They spend part of the year in sea water and part of the year on the land. (ii) The second category of swimming marine mammals includes those animals which spend their entire life in sea water such as **whales**. Whales are further divided into two families viz. (i) toothed whales, and (ii) whalebone whales. The toothed whales are predators and range in size from small size (such as sperm whales) to giant size (sich as killer whales). Dolphins and porpoises are also included in the toothed whale family. The whalebone whale family of fishes includes blue whales and humpbacked whales. Sea cow such as manatees is also important species of swimming mammals of the nekton community. Guano, mainly boobies and cormorants are important swimming birds.

3. BENTHOS COMMUNITY

The benthos community of marine organisms includes all those plants and animals which live on the sea bottoms right from the littoral marine biome to the open sea biome. The benthos community of marine organisms is charaterized by large species diversity. The total known species of the benthos animals community represents 16 percent of the total species of all the marine animals. Most of the benthos animals live on the bottom where the depth of sea water is about 200 m. In other words, most of benthos animals live on the sea botom of the photic zone having average depth of 200 m of sea water.

Benthos organisms are divided into two categories on the basis of their habitats viz. (i) epiflora and epifauna, and (ii) inflora and infauna. Epiflora and epifauna live on the surfaces of the sea bottoms whereas inflora and infauna live in the detritus and are generally buried whether completely or partially in the oceanic bottom deposits. It may be pointed out that the nature, characteristics and types of life of the benthos plants and animals are affected and controlled by several factors such as the nature and composition of sea bottom (it may be of rocky, or sandy or muddy surface), physical characteristics of sea water including temperature of sea water, amount of salinity, pressure, amount of sunlight etc. and the nature and thickness of oceanic deposits resting on the oceanic bottoms.

The important plants of sea bottoms of the littoral and continental shelve biomes are seaweeds, large algae, eelgrass (zostera) and turtle grass (Thalassia). It may be pointed out that maximum growth of the benthos plants takes place in the bottom zones of the littoral biome or littoral zone. There is well developed gradation in the plant colour from the sea coast towards the sea. For example, the colour of the littoral benthos plant gradually changes from the sea coast towards the sea in the following sequence : green weed, brown weed, and red weed. Similarly, the benthos plants developed on rocky bottoms of littoral zones range gradually from the coast towards the sea in the following sequence : channel wrack zone of facus (wrack) algae, flat wrack zone, knotted wrack zone and oar weed zone.

Benthos animals mostly include several species of mollusca which are found in large number. The important species are bivalve mussels, oysters and cockles. These animals live in hard outer shells or mantle and filter organic matter and micro-organims from sea water. These filtered organic matter and micro-organisms become food of molluscus. Echinoderms and spiny skinned animals are carnivorous benthos animals. Starish and brittle stars are important species of such spiny skinned animals. Numerous evidences of the existence of benthos animals at greater depth have been gathered. Several species of molluscus, worms, jellyfish and comb jellies have been found at the depth of 1650 m. Scarlet prawns have unique characteristic feature in that they have daily migration from the sea bottom to the upper surface of sea water during night to get food (because the upper surface of sea water is the richest zone in terms of abundance of marine plants and animals) and from the surface to the sea bottom before sunrise.

The life of marine benthic animals living on the 1000 to 4000 m deep sea bototm largely depends on the organic matter of the upper surface of sea water and the remains of nekton animals. Such deep benthos animals are generally scavengers such as sharks, sablefish, hagfish, octopus etc. There are such species of fish, squids and crustaceans living on deep sea bottoms the bodies of which emit or throw light which enables them to see in the otherwise dark environment. Hatchet fish is the most important example of such self-illuminated animals. Some deep benthos animals are endowed with illuminate lures (in other words, the bodies of such animals are covered with self-illuminated skin) which also produce light in the pitch dark environment. Octopus is very unique and conspicuous deep benthos animal because it frequently changes its colour according to the colour of its surroundings as a means of camouflage. The deepest parts of the oceans representing hadal zone ranging in depths from 6000 m to 7000 m are characterized by very few animals because of very low temperature, total absence of sunlight, near absence of nutrients etc. Among the deep benthos animals important are some detrivorous animals (feeding on detritus or sediments) such as sea cucumber (holothurians), sea anemones, crustaceans and worms. Several bacteria, sea cucumbers, brittle stars, poly chaete, sea spiders are found on the bottoms of deep sea trenches.

Ecological Productivity

The average net primary productivity of different marine biomes (according to I.G. Simmons, 1974) is 350 dry grams per square metre per year for continental shelf biome; 125 dry g/m^2 per year for open sea biome; 500 dry g/m^2/year for upwelling zone biome; and 155 dry g/m^2/year for the whole of oceanic environment. The total primary production is 9.3×10^9 tonnes per year for continental shelf biome; 41.5×10^9 tonnes/year for open ocean biome; 0.2×10^9 tonnes/year for upwelling zone biome and 55.0×10^9 tonnes/year for the whole oceanic areas.

FOOD CHAINS IN MARINE BIOME

The food chains and food webs of the marine biome are highly complex because of no effective barriers in the oceans and seas which can restrict marine animals to certain fixed localities. It may be rather convenient to discuss the feeding relationships among the marine organisms of the upper zone of the seas and the oceans or the upper pelagic biome. The phytoplanktons are the primary producers in the photic zone (upto the depth of 200 m from the sea surface) and these form the base of trophic structure of marine food chain because these green plants (mainly algae and diatoms) manufacture food through the process of photosynthesis with the help of sunlght. Thus the autotrophic primary producer phytoplanktons provide directly and indirectly food to all of the marine organisms at different trophic levels.

Zooplanktons are the heterotrophic primary consumer animals and form trophic level two of the food chain because these feed on phytoplanktons and form animal protein in their bodies.

Phytoplanktons manufacture food through the process of photosynthesis because of the availability of sunlight during day-time but the grazing of these phytoplanktons by the herbivorous zooplanktons during day-time is minimum because of the fact that most of the grazer herbivores live below the photic zone during daytime. These zooplanktons such as copepods and crustaceans come upward during night time to graze phytoplanktons. It is interesting to note that most of the nekton fishes and many benthos animals like carnivorous crustaceans also come upward during nights to catch their preys. Thus carnivorous nekton and benthos animals have easy catch of the herbivourous zooplanktons of trophic level two. These carnivorous nekton and benthos animals again return to their respective places during daytime. It may be pointed out that marine food chain is not so simple and unidirectional as mentioned above, rather it is highly complex.

13

MAN, ATMOSPHERIC ENVIRONMENT AND GLOBAL WARMING

The atmosphere, a multilayered gaseous envelope surrounding the planet earth, is a significant component of the natural/physical environment and the biospheric ecosystem because it provides all he gases necessary for the sustenance of all lifeforms in the biosphere. It also filters the incoming solar radiation and thus prevents the ultraviolet solar adiation waves to reach the earth's surface and ience protects it from becoming too hot. The tmospheric processes and the elements of weather nd climate have affected and controlled the origin, volution and development of plants and animals in he biosphere. There is mutual interaction between he components of the atmosphere and the biotic omponents of the biosphere (plants and animals). Though there are secular changes in the weather and limate at global, regional and local scales due to atural factors but since the emergence of man as the nost advanced 'technological man' the atmospheric rocesses are under tremendous changes because nan has become able and competent to change and nodify the basic structure of the atmospheric omponents through his intentional and unintenonal, direct and indirect actions. The present hapter deals with the usefulness of the atmospheric processes to human beings and the changes and modifications of the atmospheric processes brought in by man.

13.1 THE ENERGY SYSTEM

The earth and the biospheric ecosystem receives energy from three basic sources viz. (i) **solar radiation,** (ii) **gravity**, and (iii) **endogenetic forces** coming from within the earth but the solar radiation is the most significant source of terrestrial heat energy. The endogenetic forces caused by varying thermal conditions deep within the earth create relief features of varying orders and dimensions on the earth's surface which in turn affect waterflow, vegetation cover, development of soils, weather and climate etc. Gravity forces help in the downslope movement of water and ice and thus facilitate in transforming potential energy into kinetic energy.

Solar energy received through solar radiation heats the earth's surface and the atmosphere and thus is responsible for the movement of air and currents through changes in pressure gradients; drives the hydrological cycle through evaporation and precipitation which in turn helps in the cycling and recycling of nutrients and chemical elements in the biosphere through the broader cyclic pathways collectively known as **biogeochemical cycles,** helps the plants to prepare their food through the process of **photosynthesis** which in fact changes solar energy into chemical energy which is used by plants, animals and man through different trophic levels of food chains and food webs.

Radiation balance or heat balance is very important for biological communities in the biospheric ecosystem and hence a detailed discussion on global radiation and heat balance and the role of man in the alteration and maintenance of global and regional heat balances of the earth and its atmosphere is not only desirable but is also necessary for future environmental and ecological planning.

It may be pointed out that the solar energy is responsible for the functioning and maintenance of the 'earth atmosphere system' and the solar energy is received through solar radiation. Different types of weather phenomena which occur on the earth's surface depend on the mode of transfer and exchange of solar energy between the earth's surface and the atmosphere. The energy transfer from place to place takes place through the processes of conduction, convection and radiation.

13.2 FLUX OF SLOAR ENERGY IN THE BIOSPHERE

The flux or inflow of solar energy in the biosphere has been estimated differently by various scientists. Following the estimate of Ian Simmons (1982) the solar energy reaching the top of the earth's atmosphere is 520×10^{22} Joules (which is 1/2 billionth part of the total energy radiated from the sun) every year. Out of the total energy (transmitted from the sun in the form of electromagnetic radiation) about 100×10^{22} Joules reach the earth's surface but 40% of the total solar energy entering the earth's atmosphere is reflected back into space by desert, snow and ice and oceans. Thus 60×10^{22} Joules become available to the green plants for photosynthesis. This part of the solar energy is

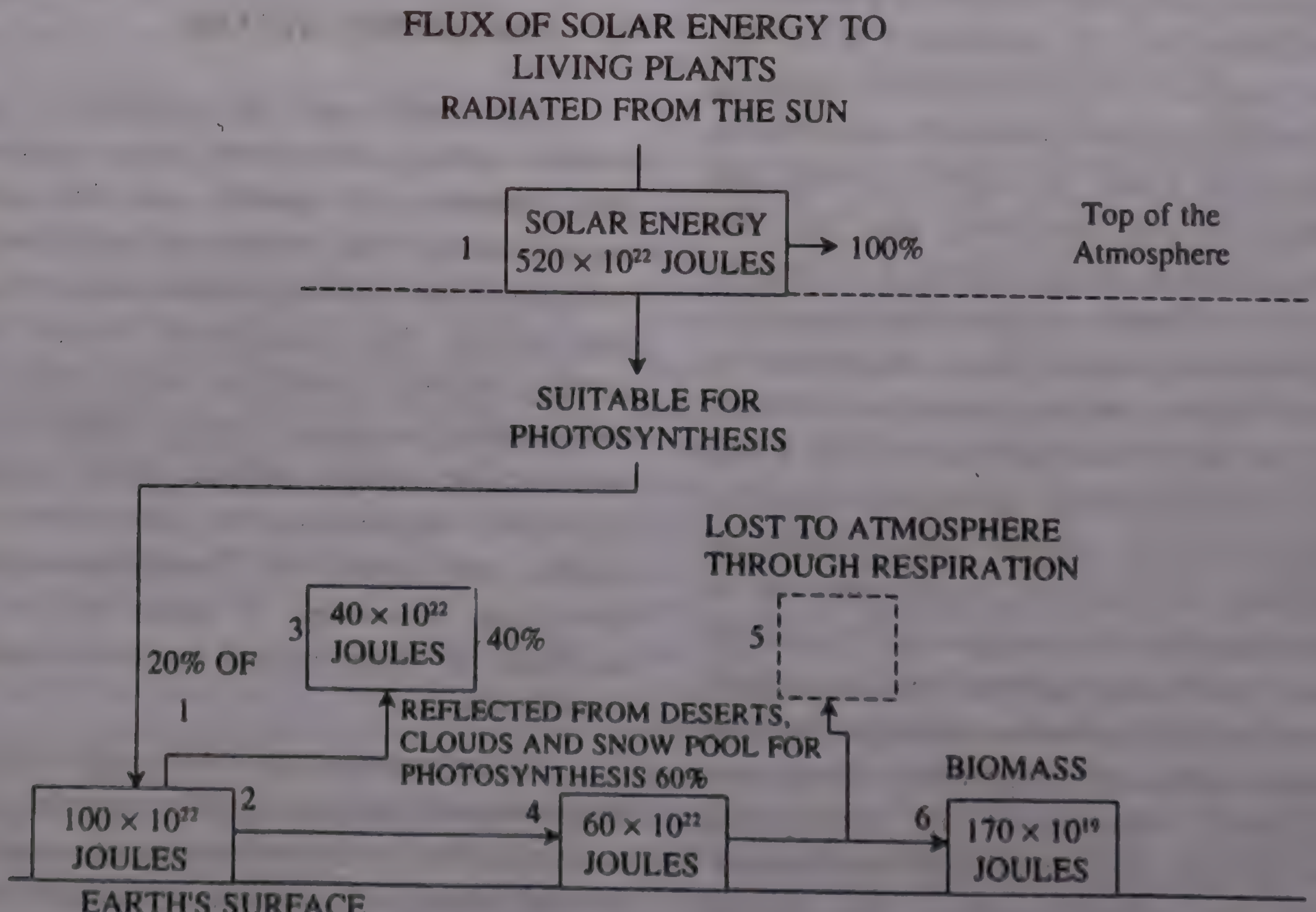

FLUX OF SOLAR ENERGY TO LIVING PLANTS RADIATED FROM THE SUN
1
SOLAR ENERGY
520 × 10²² JOULES
100%
Top of the Atmosphere
SUITABLE FOR PHOTOSYNTHESIS
LOST TO ATMOSPHERE THROUGH RESPIRATION
3
40 × 10²² JOULES
40%
5
20% OF
1
REFLECTED FROM DESERTS, CLOUDS AND SNOW POOL FOR PHOTOSYNTHESIS 60%
BIOMASS
2
100 × 10²² JOULES
4
60 × 10²² JOULES
6
170 × 10¹⁹ JOULES
EARTH'S SURFACE

Fig. 13.1 : The flow or flux of solar energy to living plants (Based on Ian Simmons, 1982).

known as **pool for photosynthesis.** This energy is converted by the green plants into food or chemical energy of which a large part is spent by the plants through respiration. Only 170×10^{19} Joules (which is only 0.2% of the total solar energy entering the earth's atmosphere) are stored in the biomass (the total mass of the living plant tissues). Thus it is obvious that the flora of the biosphere utilize only 0.2% of the total energy present in the light (solar radiation) of the right wavelength (suitable for photosynthesis by green plants). Man utilizes only less than one per cent of the total energy stored in the biomass (as accumuled organic matter, fig. 13.1).

The solar or light energy is transformed into food or chemical energy by the processes of photosynthesis by green plants. Certain part of this chemical energy is lost to the atmosphere through respiration by the plants and the remaining part is stored in the plants as biomass. The energy is further transferred from one level of organisms to the other level of organisms and it is also used and spent at various levels of organisms. Thus the flow of energy is unidirectional and once used and spent is never available for reuse. "Energy is constantly flowing into the biosphere, undergoing various transformations which may involve being stored but ultimately being lost in the form of heat" (P.A. Furley and W.W. Newey, 1983).

13.3 GLOBAL RADIATION (HEAT) BALANCE AND MAN

1. Mechanisms of Radiation

The understanding of global radiation and radiation or heat balance requires the study of radiation processes, the storage and transport of solar energy. These aspects involve the consideration of (i) input or source of energy (that is the sun), (ii) transmission and transport of energy through the atmosphere; (iii) interception or absorption of energy at the earth's surface; (iv) conversion of energy (radiant) into heat energy; (iv) heat transfer mechanisms of the atmosphere (wind and air) and the oceans (waves and currents), and (vi) the mechanism of output of energy by the earth in the form of secondary radiation or the terrestrial radiation.

The prime source of heat energy of the earth and its atmosphere is the sun which is a great engine that drives winds on the earth's surface, ocean currents, exogenetic or denudatinal processes and ultimately sustains life in the biosphere. Though the earth receives a very small amount of total energy emitted from the sun's surface (1/2 billionth part of the sun's total energy output) yet this meagre amount of solar radiation is sufficient enough to sustain life in the biosphere.

The source of energy of the sun is its interior wherein the hydrogen is converted into helium due to enormous confining pressure and very high temperature under the process of nuclear fusion which generates huge quantity of heat. This heat is transported to the outer surface of the sun through convection and conduction from below. It may be pointed out that the rate of generation of heat inside the sun is more or less constant and hence the radiation of energy from the outer surface of the sun (called as **photosphere**) is also more or less constant. Thus, the amount of solar radiation or the solar energy received on a unit area of the surface facing the sun at the average distance between the sun and the earth is also more or less constant and is called as **solar constant.** Thus, it is obvious that the solar constant refers to the rate of radiation from the sun which is of the value of 2 gram calories per square centimetre per minute ($2\ cal/cm^2/min$). It is also expressed in terms of langley (a unit measure of heat energy, one gram calorie per square centimeter is equal to one langely) as 2 langely per minute (2 ly/min).

There are two basic laws which govern the nature and flow of radiation as given below :

(1) **Wien's displacement law** 'states that the wavelength of maximum radiation is inversely proportional to the absolute temperature of the emitting body.'

Thus, the higher the temperature of radiating body, the shorter the wavelength and vice versa. This law may be explained with the example of wavelengths of the radiation waves of the earth and the sun. It may be mentioned that the average temperatures of the surface of the earth and the sun are 288^0K and 6000^0K respectively.

λmax (wavelength in micrometer) = K/T

where K is constant (2897)

T is temperature in degrees Kelvin

(i) In the case of the sun the wavelength of solar radiation waves = $\lambda max = 2897/6000^0K$

= 0.48 micrometer

(ii) In the case of the earth the wavelength of terrestrial radiation waves = $\lambda max = 2897/288^0K$

= 10 micrometers

It is evident from the above examples that the wavelengths of terrestrial radiation waves are much longer than those of the solar radiation waves.

(2) **Stefan-Boltzman law of radiation** states 'that flow, or flux, of radiation is proportional to the fourth power of the absolute temperature of the radiating body.'

It may be mentioned that **Wien's displacement law, Stefan-Boltzman law, Kirchoff's law, Plank's law** etc. are related to radiation from the **black body.** A black body is that hypothetical body of object which absorbs all incoming electromagnetic radiation without reflecting any amount of incident energy and radiates energy. The sun and the earth though not perfect black bodies, are approximately black bodies.

Stefan - Boltzman law states :

$F = \sigma T^4$

Where F = flux of radiation from per square meter surface area of the radiating body

σ = is a constant equivalent to 5.67×10^{-8} W/m^2 K^4 in SI units

T = is the temperature of the radiating body in degree Kelvin.

The Stefan-Boltzman law simply states that 'the hotter the radiating body, the greater the amount of energy radiated from that body and vice versa.' This can be explained with the temperatures of the outer surfaces of the sun and the earth. As stated above the temperatures at the surfaces of the earth and the sun are 288^0K and 6000^0K respectively. Thus, the sun's surface is much hotter than the earth's surface, say the sun's surface is roughly 20 times hotter than the earth's surface. 'Twenty raised to the fourth power is 160,000. Therefore, the sun emits 160,000 times as much radiation per unit area as earth's (Oliver and Hidore, 2003).

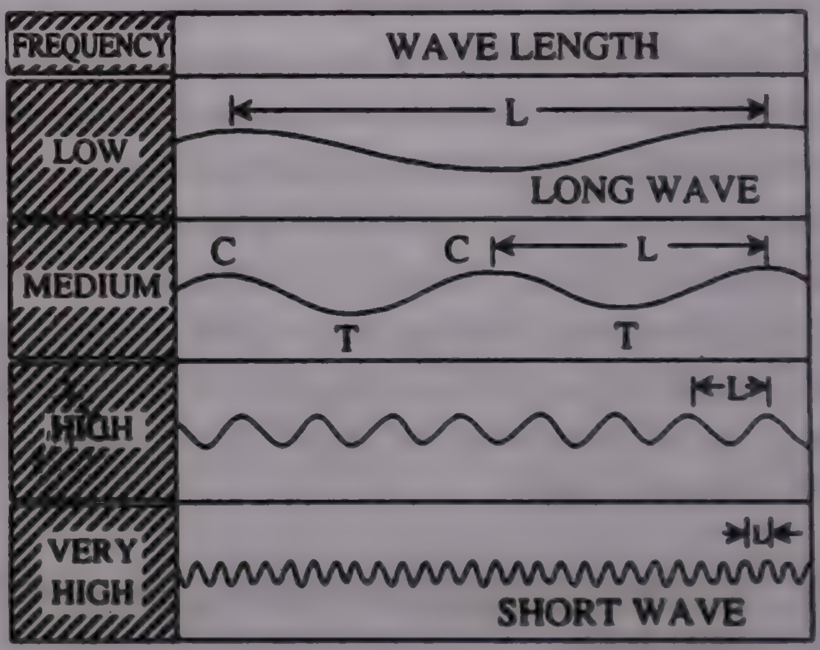


Fig. 13.2 : Relationship between wavelength and wave frequency, L = wavelength, C = wave crest, and T = wave trough.

The **Kirchoff's law** is related to the absorption of radiation and emission of radiation from a body. The law states, the higher the absorption of radiation of a body, the greater the emission of radiation from that body.

The surface temperature of the sun is 6000^0K. The highly incandescent gas of the sun's surface being heated from below emits bundle of energy called **'photon'** which is in fact the particle of radiation which has the property of wavelength. Continuous emission of **photons** from the sun's surface causes continuous bands of radiation having certain wavelength which is considered as short wavelength in relation to the earth's outgoing longwave radiation. The solar energy radiated from the outer surface of the sun in the form of electromagnetic wave is called as **electromagnetic radiation,** which travels at the speed of 3,00,000 km per second (1,86,000 miles per second). The solar energy received at the earth's surface is called **insolation** or **solar radiation.**

The energy from the sun is emitted in the form of electromagnetic waves which travel outward in radial manner from the sun almost in straight line and take 8 minutes 20 seconds to reach the earth's surface after covering an average distance of 150 million km (93 million miles) between the sun and the earth. The electromagnetic radiation waves are expressed in terms of **wavelengths** (L). The straight distance between two successive crests or troughs is called wavelength (fig. 13.2) (L) which is expressed in the length units of meters, centimeters, millimeters, microns etc.

Table 13.1 : Wavelengths of shortest waves

Waves	Wavelength (in angstrom)	Frequency of wavelenghs (in megaherts)
1. Gama Rays	Less than 0.03	10^{14}
2. Hard X-Rays	0.03-0.6	10^{13}
3. Soft X-Rays	0.6-100	10^{12}-10^{11}
4. Ultra-Violet Rays	100-4000	10^{10}-10^{9}

The number of radiation waves (one radiation wave is equal to one wavelength) passing through a certain point per unit time (usually one second) is called **wave frequency** which varies according to the wavelengths of the radiation waves. There is inverse relationship between the wavelength, and wave frequency i.e. shorter the wavelength, higher the wave frequency and longer the wavelength, lower the wave frequency (fig. 13.2). In other words, high wave frequency is associated with short wavelength and low wave frequency is associated with long wavelength. Wave frequency is generally expresed as wave cycles per second. The wave cycles are usually expressed by the unit of measure of hertz. For example, one hertz per second represents one wave cycle meaning thereby only one wavelength passes per second from a fixed point. Hertz is further expressed in kilohertz (1,000 hertz) or megahertz (1,000,000 hertz).

The electromagnetic radiation emitted from the outer surface of the sun consists of four spectra of radiation waves having different wavelengths and wave freqeuencies.

(1) **The first spectrum** of electromagnetic waves includes **gama rays, hard x-rays, soft x-rays** and **uttraviolet rays.** The wavelengths of this spectrum of the shortest wavelengths are expressed in the unit measure of angstrom wherein one **angstrom** is equal to 0.000,000,01 cm or 10^{-8}cm. The wavelengths of the waves of the spectrum of the shortest waves are given in table 13.1.

(2) **The second spectrum** of the electromagenetic radiation waves is also called as the **spectrum of visible light** or **rays** which includes violet, blue, green, yellow, orange and red rays which carry 41 per cent of the total energy of the solar spectrum of all the electromagnetic radiation waves. The unit of the measure of wavelengths of this spectrum is micron (one micron is equal to 0.0001 cm or 10,000 angstroms). The wave frequency of these different rays ranges between 10^{10} and 10^{9} megahertz per second. The wavelengths of these visible rays are as given below :

Visible rays	Wavelengths in microns
1. Violet rays	0.4-0.43
2. Blue rays	0.43-0.49
3. Green rays	0.49-0.53
4. Yellow rays	0.53-0.58
5. Red rays	0.58-0.70

(3) **The third spectrum** of the electromagnetic radiation waves is called as **infrared spectrum** which consists of infrared waves of the wavelengths ranging from 0.7 micron to 300 microns. The wave frequency ranges between 10^{8} and 10^{6} megahertz per second.

(4) **The fourth spectrum** of the electromagnetic radiation wave consists of long waves including microwaves, radar waves and radio waves. The unit measure of these wavelengths of longwaves is usually centimetre to metre. The wavelengths of microwaves range between 0.03 cm and 1.0 cm. These waves are used to send messages from one place to other distant places. The wavelengths of radar waves vary from 1.0 cm to 100 cm (1m). The **radar system** is divided into two sub-systems on the basis of frequency viz. (i) **radio system,** and (ii) **television system.** The radar, television and radio waves are divided into 6 categories on the basis of wave frequency and wavelengths.

Frequency	Wavelengths
1. Extremely High Frequency (EHF)	0.1 - 1.0 cm
2. Super High Frequency (SHF)	1.0 cm - 10.0 cm
3. Ultra-High Frequency (UHF)	10.0 cm-100.0 cm
4. Very High Frequency (VHF)	1.0 m - 10.0 m
5. High Frequency (HF)	10 m - 100 m
6. Low Frequency (LF)	more than 100 m

2. Transport of Solar Radiation Through the Atmosphere

The electromagnetic radiation or the incoming short wave solar radiation has to pass through thick layer of the earth's atmosphere and therefore it plays a significant role in affecting the transport of solar energy to the earth's surface via atmosphere. The electromagnetic solar radiation while passing through the atmosphere is partly absorbed, partly reflected, partly scattered and partly transmitted through the surface of the planet earth.

If the total amount of energy radiated towards the earth and its atmosphere is taken to be 100 per cent (1/2 billionth part of the total energy radiated from the outer surface (**photosphere**) of the sun), about 14 per cent is absorbed by the atmospheric gases (e.g. by ozone in the stratosphere, oxygen and carbon dioxide to very limited extent), water vapour (H_2O), dust and haze. Some portion of the incoming electromagnetic solar radiation (about 23%) is scattered in the atmosphere by dust particles and haze. The part of this scattered energy (about 6%) is sent back to the space while major portion of this scattered solar energy reaches the earth's surface (about 17 per cent of the incoming solar radiation). The process of **scattering** is selective in nature. Scattering becomes possible when the diameter of invisible dust particles (aerosols) suspended in the air and the molecules of the atmospheric gases is shorter than the wavelengths of the solar radiation waves. Blue light of the incoming shorter wavelength is more scattered than red light. This is the reason that the sky looks blue. Similarly, the picturesque colours of the sky during sunrise (dawn) and sunset (twilight) are the result of scattering of incoming solar radiation (of certain wavelengths only).

Absorption of incoming solar radiation by the atmospheric gases, water vapour, haze etc. is also selective in nature. The shortest wavelengths ranging between 0.02 micron and 0.29 micron are absorbed by oxygen (O_2) and ozone (O_3) gases. Ozone also absorbs ultraviolet rays of the wavelengths varying from 1000 angstroms to 4000 angstroms and thus prevents these ultraviolet radiation waves from reaching the earth's surface. Water vapour absorbs the incoming solar radiation waves when their wavelengths range between 0.9 micron and 2.1 microns.

The scattering of incoming solar radiation by dust particles and molecules of water vapour (clouds), when the diameter of these particles is longer than the wavelengths of incoming solar radiations is called **diffuse reflection** which sends some portion of incoming solar energy back to the space and some portion remains in the lower atmosphere. The diffused and scattered solar energy present in the lower atmosphere enables us to see even the dark portion of the moon. One can also see (if not suffering from cataract) even in the pitch darkness of night. Some of the scattered and diffuse solar energy reaches the ground surface. Such energy is called as **diffuse blue light of the sky or diffuse day light.** Some portion of incoming solar radiation is reflected back to space by high clouds (about 27 percent of the total incoming solar radiation) and by the ground surface (about 2 per cent).

The proportion of incident radiant energy reflected back by a surface is called **albedo.** Various attempts have been made to measure total albedo of the earth (including its atmosphere). Various data derived so far indicate the earth's average albedo fluctuating between 29 percent and 34 percent (including the energy reflected through the mechanism of **difuse reflection** by dust particles, water molecules etc., from the cloud surface and from the earth's surface). The albedo of other planets has also been estimated e.g. Moon (7 percent), Mercury (6 percent), Mars (16 percent), Venus (76 percent) and the remaining outer planets (ranging between 73 per cent to 94 per cent). It may be pointed out that the processes of absorption, scattering and reflection are not as simple as discussed above rather these are highly complex. Furthermore, the figures used here to indicate the quantity of solar radiation lost during its passage through the atmosphere by different processes are mere estimates and these vary from the estimates of one scientist to the other scientists.

3. Global Heat Balance of the Earth and the Atmosphere

'The total solar radiation reaching a horizontal surface on the ground is called **global radiation.** It comprises the direct shortwave radiation from the sun, plus the diffuse radiation scattered by the atmosphere' (J.E. Hobbs, 1980). On an average, there is supposed to exist heat balance between the amount of solar radiation received by the earth's surface and its atmosphere and the amount of heat lost by the outgoing terrestrial longwave radiation from the earth's surface and loss of heat from the atmosphere. It may be pointed out that the solar energy received at the earth's surface is converted into heat energy which heats the outer surface of the earth. Thus, the earth after being heated also radiates energy in the form of longwave radiation. The radiation from the sun towards the earth and from the earth towards the atmosphere and the space is called **incoming shortwave solar radiation** (radiation from the sun) and **outgoing longwave terrestrial radiation** (from the earth) respectively.

The heat budget of the earth and the atmosphere displaying statement of receipt of solar radiation by the atmosphere and the earth's surface and the loss of energy by the earth and the atmosphere known as terrestrial radiation is also called **energy balance of the earth and the atmosphere** or **global radiation balance.**

On an average, the solar radiation reaching the outer boundary of the earth's atmosphere is estimated as follows :

total solar radiation
at the otuer boundary of = solar constant $\times \pi r^2 / 4\pi r^2$
the atmospehre

where r = radius of the earth
$4\pi r^2$ = surface area of the earth (both land and sea surfaces)
= 11×10^9 Jm^{-2} yr^{-1}
where J = Joules (the SI unit of energy, equivalent to 10^9 ergs and one watt-second)
10^9J = one GJ (G-giga means one billion)
J = Joules

The total incident solar radiation (energy) reaching the outer margin of the earth's atmosphere is taken to be 100 units or 100 per cent for the explanation of heat/energy budget of the earth and the atmosphere. Two examples based on the data of (1) G.T. Trewartha, and (2) Oliver and Hidore are given below to explain the heat/energy budget (balance) :

1. Based on G.T. Trewartha

The total incident radiation at the outer margin of the earth's atmosphere is taken as 100 percent (fig. 13.3) and hence all the data used in the explanation of heat budget are in percentage.

(1) Incoming Shortwave Solar Radiation and the Heat Budget of the Earth and the Atmosphere

The earth receives most of its energy from the sun through shortwave solar radiation. The solar energy radiated towards the earth's surface (1/2 billionth part of the total energy radiated from the outer surface (**photosphere**) of the sun which is equivalent to 23 trillion horse power) is taken as 100 per cent or 100 units. Out of the total incoming solar radiation entering the earth's atmosphere 35 per cent is sent back to space through scattering by dust particles (6%), reflection from the clouds (27%) and from the ground surface (2%), 51 percent is received by the earth's surface (received as direct radiation), and 14 percent is absorbed by the atmospheric gases (ozone, oxygen etc.) and water vapour in different vertical zones of the atmosphere. The 51 per cent solar energy received by the earth comprises 34 per cent as direct solar radiation and 17 per cent as **diffuse day light.** The heat budget of the atmosphere comprises 48 per cent of solar radiation wherein 14 per cent is received through absorption of the shortwave incoming solar radiation and 34 per cent is received from the outgoing long wave terrestrial radiation.

Table 13.2 : Simplified global radiation/heat budget of the earth and the atmosphere (based on G.T. Trewartha)

(1) Incoming Shortwave Solar Radiation (in percentage)		
Total energy reaching the top of the atmosphere		100
(A) The amount of solar radiation lost (depleted) during its passage through the atmosphere (a + b + c)		35
(a) reflected from the clouds	27	
(b) reflected from the ground surface	2	
(c) scattered and diffused by the dust particles and molecules of water vapour and sent back to space	6	
Remaining amount of solar radiation available for the earth and its atmosphere (100-35)		65
(B) Terrestrial heat receipt (gained by the earth's surface) (a + b, 34 + 17 = 51)		51
(a) received through direct radiation	34	
(b) received through diffuse day light	17	
(C) Atmospheric heat receipt (gained by the atmosphere) from incoming solar radiation and outgoing terrestrial radiation, (a + b, 14 + 34)		48
(a) received through absorption of incoming solar rediation by ozone, CO_2, oxygen, water molecules etc.	14	
(b) received through outgoing terrestrial radiation	34	
(2) Outgoing Longwave Terrestrial Radiation and Heat Balance of the Earth and the Atmosphere		
(A) Energy received by the earth	(B) Energy lost by the earth (a + b + c, 23 + 9 + 19 = 51)	51

Total energy received by the earth	51	(a) lost through direct radiation	23
		(b) spent in convection and turbulence	9
		(c) spent in evaporation	19
(3) Heat Balacne of the Atmosphere			
(A) Total energy received by the atmosphere	48	(B) Energy lost from the atmos-spahere to space	48
(a) received through absorption of incoming shortwave solar radiation	14		
(b) received through effective radiation from the earth	6		
(c) received through convection and turbulence	9		
(d) received as latent heat of condensation	19		
Total amount received by the atmosphere (a +b+c+d)	48	Total amount lost by the atmosphere	48

Atmospheric (heat /energy balance = gain (48) - loss (48) = 0

Source of data : G.T. Trewartha

(2) Outgoing Longwave Terrestrial Radiation and Heat Balance

After receiving energy from the sun (fig. 13.3) the earth also radiates energy out of its surface into the atmosphere through longwaves (fig. 13.3). The terrestrial radiation is also called **'effective radiation'** because it helps in heating the lower portion of the atmosphere. Twenty three per cent energy (out of 51% energy which the earth has gained from the sun) is lost through direct longwave outgoing terrestrial radiation out of which 6 per cent is absorbed by the atmosphere and 17 per cent goes directly to the space. About 9 per cent of the terrestrial energy is spent in convection and turbulence and 19 per cent is spent through evaporation which is added to the atmosphere as latent heat of condensation. Thus, the total energy received by the atmosphere from the sun (14%) and the earth (34%) becomes 48 per cent which is reradiated to the space in one way or the other.

It may be mentioned, that the model of heat balance of the earth and the atmosphere as presented by G.T. Trewartha is over simplified because it does not consider the counter radiation (reradiation) of terrestrial radiation by the atmospheric vapour and clouds. It is significant to note that a sizeable portion of heat radiated from the earth is returned back to the earth's surface by water vapour, carbon dioxide etc. after absorbing terrestrial radiation. In fact, a part of ground radiation after being absorbed by the atmosphere is radiated back to the earth's surface. This process of reradiation of terrestrial heat energy from the atmosphere back to the earth's surface is

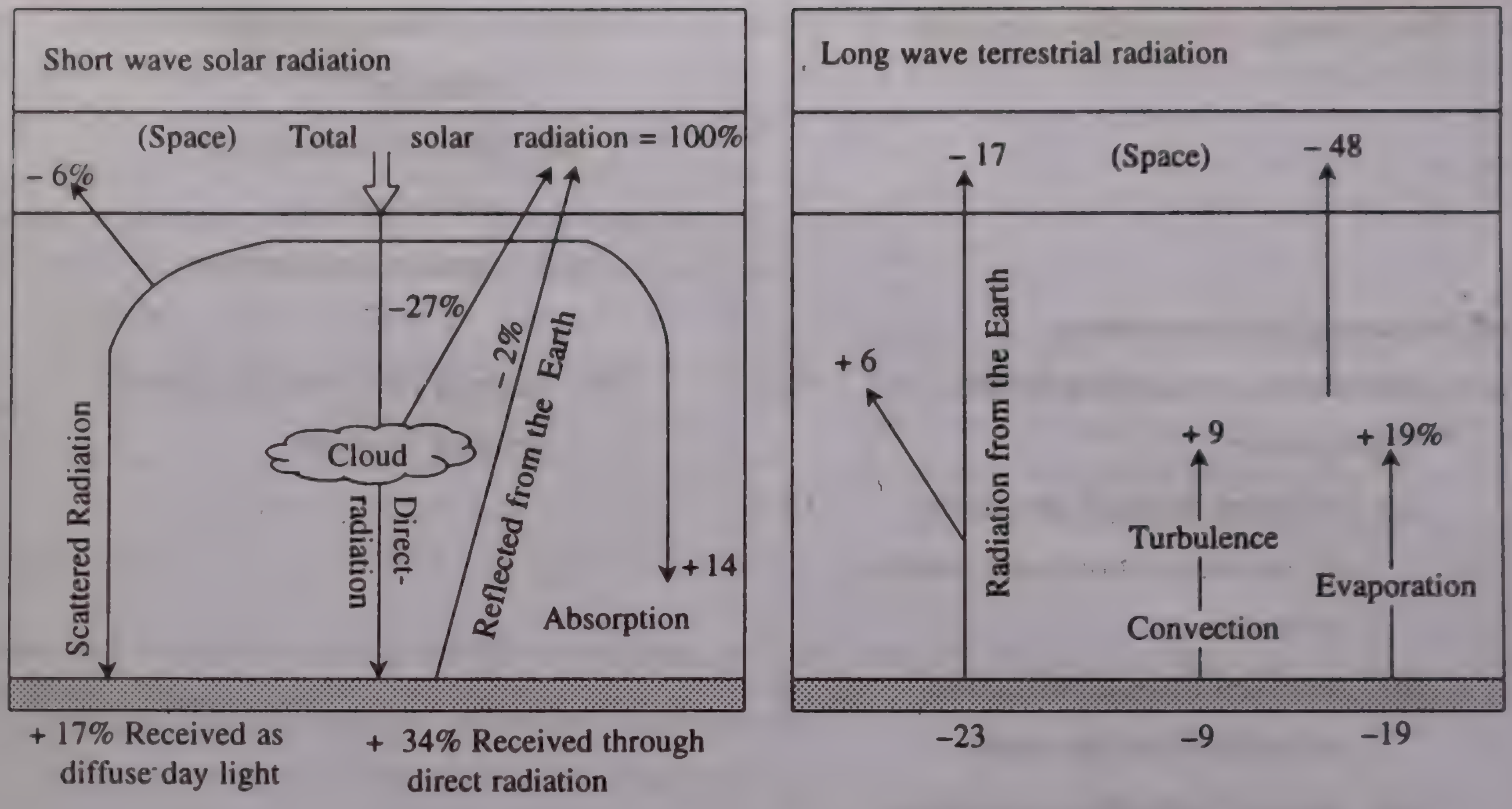

Short wave solar radiation
(Space) Total solar radiation = 100%
- 6%
-27%
- 2%
Cloud
Scattered Radiation
Direct-radiation
Reflected from the Earth
+ 14
Absorption
+ 17% Received as diffuse day light
+ 34% Received through direct radiation
Long wave terrestrial radiation
- 17
(Space)
- 48
+ 6
Radiation from the Earth
+ 9
+ 19%
Turbulence
Convection
Evaporation
-23
-9
-19

Fig. 13.3 : Radiation or heat balance of the earth and the atmosphere.

called **counter-radiation** which is effected mainly by water vapour and atmospheric carbon dioxide. This mechanism known as greenhouse effect keeps the lower atmosphere and ground surface relatively warmer. Thus, it is imperative to include reradiation of terrestrial energy back to the atmosphere and the space in the consideration of heat/energy budget (balance) of the earth and the atmosphere. So, the second example of a comprehensive model of Oliver and Hidore is presented below.

2. Based on Oliver and Hidore

Oliver and Hidore have included counter-radiation by the atmospheric water vapour and gases in their model of heat/energy balance of the earth and the atmosphere and have referred **counter-radiation** as **skyradiation.** They have used units to explain the solar energy, earth energy and atmospheric energy wherein one unit is equal to 1/100 of the total solar radiation which reaches the top of the earth's atmosphere. Table 13.3 explains the heat/energy balance of the earth and the atmosphere.

Table 13.3 : Energy (heat) balance (budget) of the Earth and the Atmosphere (number indicates unit)

Total Solar Radiation Reaching the outer Boundary of the Earth's Atmosphere		100
Gain of energy by the earth (inflow)		
(a) through direct radiation absorbed by the earth's surface	50	
(b) through longwave sky-radiation (counter-radiation or reradiation from the lower atmosphere) (absorbed by the earth's surface)	96	

(A) Total energy gained by the earth	146
(a + b, 50 + 96 = 146)	
Loss of energy from the earth's surface (outflow)	
(a) radiation loss in the form of sensible heat	12
(b) longwave radiation from the earth's surface to the atmosphere	107
(c) loss in the form of latent heat	20
(d) longwave radiation from the earth's surface to space	7
(B) Total loss of energy from the earth	
(a + b + c + d) (12 + 107 + 20 + 7)	146
1. Heat Balance of the Earth's surface	146-146= 0 (balance)
(A – B) (146 - 146 = 0)	
Gain of heat energy by the atmosphere (inflow)	
(a) solar radiation directly absorbed by the atmosphere	20
(b) latent heat of condensation	20
(c) longwave radiation from the earth's surface	107
(d) through conduction from the earth's surface as sensible heat	12
(A) Total energy gained by the atmosphere	
(a + b + c + d) (20 + 20 + 107 + 12)	159
Loss of heat energy from the atmosphere (outflow)	
(a) Long wave radiation from the atmosphere to space	63
(b) longwave sky radiation (counter-radiation to the earth's surface)	96
(B) Total loss of heat energy from the atmosphere (a+b, 63+96)	159
2. Heat Balance of the Atmosphere	159-159= 0 (balance)
(A - B, 159 - 159 = 0)	
3. Heat Balance of the Earth-Atmosphere	
(A) Inflow of energy	
solar radiation reaching the outer limit of the atmosphere	100
Total inflow	100
(B) Outflow of energy	
(a) sent back to space by reflection and scattering	30
(b) longwave radiation from the atmosphere to space	63
(c) longwave radiation from the earth's surface to space	7
Total outflow (a + b + c, 30 + 63 + 7)	100

Source of data : Oliver and Hidore, 2003

It is evident from table 13.3 that out of the total solar radiation (100 units) reaching the outer limit of the earth's atmosphere 30 units are sent back to space by the atmosphere through the processes of reflection and scattering while 7 units are sent back to space from the earth's surface as direct longwave radiation. Thus, 37 units (30+7) of incoming solar radiation, sent back to space by the atmosphere and the earth's surface, are of no use in heating the earth's surface and the atmosphere. Only 63 units (100-37) of energy are available to the earth's surface and the atmosphere.

The inflow of solar radiation to the earth's surface comprises 146 units of energy which are received through direct solar radiation and scattered energy (50 units) and through counter radiation or sky radiation from the atmosphere (due to greenhouse effect) (96 units). Thus, the total gain of solar radiation by the earth's surface becomes 146 units. The heat energy received by the earth's surface (146 units) is spent in evapotranspiration (20 units), conduction (as sensible heat, 12 units), direct radiation to the atmosphere (107 units) and the space (7 units). Thus, the total loss of energy from the earth's surface becomes 146 units (20 + 12 + 7 + 107 = 146 units). This demonstrates a steady state balance of heat energy of the earth's surface (gain of 146 units - loss of 146 units = 0, balance).

The atmosphere receives 159 units of heat energy comprising 20 units through direct absorption of incoming solar radiation by atmospheric gases (mainly carbon dioxide and ozone) and water vapour, another 20 units from condensation and latent heat, 107 units from longwave radiation from the earth's surface and 12 units through conduction (sensible heat) from the earth's surface. Thus, the total gain of heat energy by the earth's atmosphere becomes 159 units. The heat energy from the atmosphere is lost through (i) longwave radiation of 63 units to space, and (ii) longwave sky radiation (counter-radiation) of 96 units to earth's surface. Thus, total loss of heat energy from the atmosphere becomes 159 units (63 + 96 = 159 units). This demonstrates balance between the gain of heat energy (159 units) and loss of heat energy (159 units) from the atmosphere.

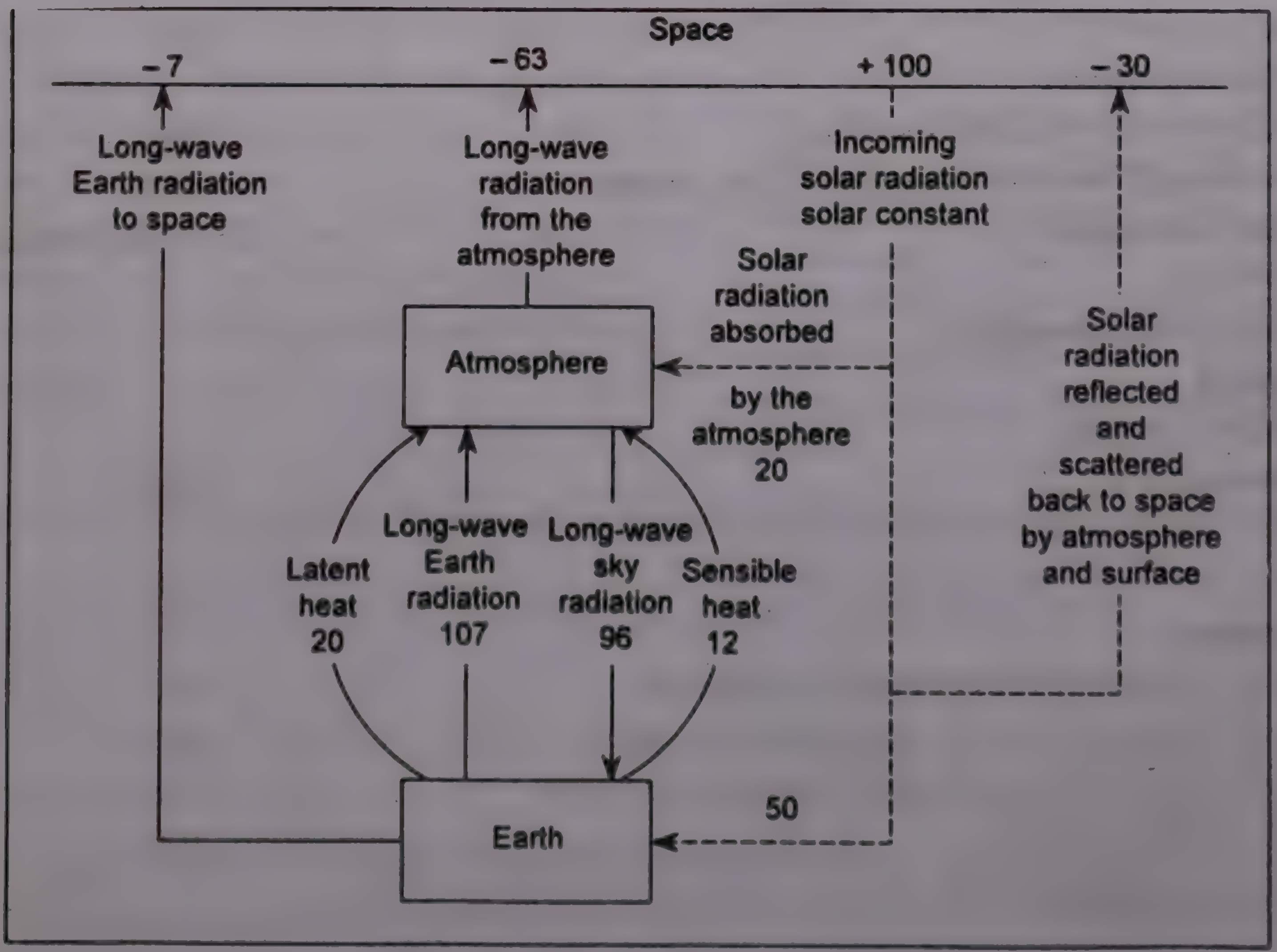

Space
-7
-63
+100
-30
Long-wave Earth radiation to space
Long-wave radiation from the atmosphere
Incoming solar radiation solar constant
Solar radiation absorbed by the atmosphere 20
Solar radiation reflected and scattered back to space by atmosphere and surface
Atmosphere
Latent heat 20
Long-wave Earth radiation 107
Long-wave sky radiation 96
Sensible heat 12
50
Earth

Fig.13.4 : Heat (energy) balance of the earth and the atmosphere. After-J.E. Oliver and J. J. Hidore, 2003.

The 100 units of incoming solar radiation is balanced by 30 units of energy sent back to space by scattering and reflection by the atmosphere, 63 units sent back to space by atmopsheric longwave radiation and 7 units sent back to space from the earth's surface (30 + 63 + 7 = 100 units).

Oliver and Hidore (2003) maintain that 'the earth is in a steady-state balance of incoming and outgoing energy. The temperature (average) of the earth undergoes small changes, but the mean temperature stays nearly the same. It varies only slightly around 15°C (59°F) at the surface, although there are daily, seasonal and year to year changes...There is a built in storage mechanism known as the greenhouse effect that raises the temperature such that life can exist' (Oliver and Hidore, 2003).

13.4 NET RADIATION AND LATITUDINAL HEAT BALANCE

The difference between all incoming solar energy and all outgoing terrestrial energy by both shortwave and longwave radiation is called **net radiation.** It is apparent from the aforesaid discussion that the net radiation from the whole globe is at least theoretically zero but this is far from truth if we look at the regional distribution of insolation. There are some places where the receipt of solar energy is more than the energy lost because the solar energy comes at faster rate than the terrestrial energy goes out. Similarly, in some areas the loss of energy through outgoing terrestrial radiation is faster than the gain of incoming solar radiation. This mechanism results in the development of areas of **energy surplus** (where incoming solar radiation exceeds outgoing terrestrial radiation) and **energy deficit** (where outgoing terrestrial radiation exceeds incoming solar radiation).

Table 13.4 : Annual meridional heat transport

Latitudes (northern hemisphere)	Heat transport (kilocalories per year × 10^9)	Latitudes (northern hemisphere)	Heat transport (kilocalories per year × 10^9)
90	0.00	40	3.91
80	0.35	30	3.56
70	1.25	20	
60	2.40	10	2.54
50	3.40	0 (equator)	-0.26

Source : W.E. Sellers, 1965

The energy surplus and energy deficit areas may be identified and studied at two levels viz. (i) **at the earth's surface,** and (ii) **in the atmosphere,** latitudinal base being common in both the cases. (i) The distribution of net radiation at the earth's surface from equator towards the poles shows that (a) there is large **energy surplus area** between the zones of 20°N and 20°S where energy gain from the incoming solar radiation is more than the loss of energy through outging longwave terrestrial radiation and the annual surplus energy amounts to 100 kilo langleys per year; (b) net radiation rapidly decreases from the energy surplus areas of low latitudes towards mid-latitudes; (c) net radiation becomes practically zero near 70° latitude in the northern and southern hemispheres, and (d) the polar areas are the zones of perennial **energy deficit.**

(ii) The latitudinal distribution of net radiation in the atmosphere shows that 'the atmosphere is itself a net loser of radiation at all latitudes' (J.E. Hobbs, 1980). Thus, the atmosphere is the zone of perennial energy deficit because the deficit of energy always exceeds 60 kilo langleys per year. If the data of net radiation of both, the earth's surface and the atmosphere, are combined together, the net radiation value for the combined **'earth's surface-atmosphere system'** may be calculated. Based on the combined data the following energy zones are identified, (a) large region of surplus radiation extending between 40^0N and 30^0S latitudes, (b) northern high-latitudes of deficit radiation, and (c) southern high-latitudes of deficit radiation (A.N. Strahler, 1978).

It means that "there must exist a two-way heat transfer; from the earth's surface to the atmosphere and from the equator to the poles" (J.E. Hobbs, 1980). This can be achieved if heat is transported from the earth's surface to the atmosphere and from the tropical and subtropical areas of surplus radiation to the high latitude zones of deficit radiation. The transport of heat from equatorial area towards the poles is called **'meridional transport of heat'.**

The meridional transport of heat energy in the form of **sensible heat** is accomplished by the atmospheric circulation and ocean currents which transport heat energy from the 'low latitude surplus energy areas' to the 'high latitude deficit energy areas'. The vertical transport of heat in the atmosphere is accomplished by ascending air in the form of sensible heat and latent heat. Table 13.4 portrays latitudinal transfer of sensible heat.

13.5 HUMAN INFLUENCE ON RADIATION (HEAT) BALANCE

Radiation balance or heat balance is very important for the biological communities including both plants and animals together with micro-organisms and man. The changes in the radiation balance may be grouped in two classes viz. (i) **natural changes,** and (ii) **man-induced changes** or **anthropogenic changes.** Natural changes in the global radiation/heat balance take place due to (i) periodic changes in **solar constant,** (ii) alteration of the transparency of the atmosphere through the addition of enormous quantity of dust and smoke to the atmosphere ejected through volcanic eruption (volcanic dust in the atmosphere reduces the shortwave solar radiation reaching the earth's surface), and (iii) the global climate changes due to movement of continents and ocean basins in relation to poles due to the mechanism of plate tectonics.

Besides these and many more natural changes of solar radiation balance and weather and climate, man is also capable of changing and altering the radiation balance and weather and climate from local through regional to global scales.

(1) **At Local Level :** Man has largely been responsible to affect and modify the radiation balance through his activities e.g. increasing urbanisation and expanding industrialisation. Increasing urbanisation means covering of more and more bare ground surface by 'pucca structure' which sets off a chain of effects and counter-effects viz. sprawling urban areas change the thermal properties of the ground surface, reduce the albedo, change the aerodynamic character of the surface, alter the pattern of air circulation, lower the speed of wind, reduce total insolation, increase mean annual temperature and create **heat island** in the city centre and **pollution dome** in the lower atmosphere above the major urban centres. Expanding industrialization causes addition of enormous quantity of dust and gases (mostly toxic and poisonous) through **human volcanoes** (factories) to the lower atmosphere and thus changes the heat balance at local level which is also extended to regional level in the highly urbanised and industrialized countries where several industries of large industrial belts intensify the greenhouse effects.

Two case studies of Budapest city (Hungary) and Hamilton (Ontario, Canada) industrial area may illustrate the influences of urbanisation and industrialization on radiation balance at local level. D. Greenland (1981) has reported that there is decrease in the annual mean incoming shortwave solar radiation upto the tune of 7to 8 per cent near the city centre of Budapest whereas F. Probald (1972) has maintained that the decrease in the incoming solar radiation in the city centre of Budapest during winter months (November to March) caused by polluted air over the city rises to 15 per cent or even more. The conversion of larger ground area into 'pucca structure' has markedly reduced the albedo of the city. This reduced albedo compensates the loss of reduced incoming solar radiation because decrease in surface albedo means decrease in the loss of heat through reflection from the surface. The study of Budapest city further reveals that the longwave radiation from the surface has also increased but the effect of this process is negated because of increased longwave radiation from the atmosphere back to the surface as a result of **counter-radiation** which is because of accumulating greenhouse gases (carbon dioxide) in the lower atmosphere over the city of Budapest. W.R. Rouse and J.G. McCutcheon (1972) have reported similar situation in the industrial city of Hamilton as they have reported an overall decrease of 9% to 17% in the incoming solar radiation and 11% increase in the longwave downward radiation from the atmosphere as counter radiation. D. Greenland (1981) has concluded that 'it is interesting to note, however, that the changes in the various radiant flows tend to balance each other out, leaving the net radiation of the urban surface rather similar to that of the surrounding surfaces. The effect of increased longwave radiation countering decreased shortwave radiation was seen in both Budapest and Hamilton'.

(2) **At Regional Level :** The change of radiation balance at **regional level** is caused due to weather modification programmes viz. cloud seeding to induce more precipitation, prevention of hailstorms, dispersion and diversion of clouds and other human activities like melting of ice through the use of carbon-black dusts on the ice-covered surface, diversion of atmospehric storms etc. Land use changes affect the radiation balance in a variety of ways at regional scale. According to the report of SMIC (1971, Study of Man's Impact on Climate, Massachusetts, U.S.A.) 18 to 20 per cent of land surface of the earth has been changed by man for agricultural purposes. The change in land use, mainly through deforestation for increase in cropland, changes the albedo (reflection of incoming solar radiation) of the earth's surface which then changes the radiation balance. According to the report of SMIC the clearance of coniferous forest (of which the albedo is 12 per cent) or deciduous forest (albedo being 18 per cent) for agricultural land (albedo being 20 per cent) results in increase of surface albedo and hence decrease in the absorption of solar radiation. Thus land use changes from forest cover to agricultural land reduce the net radiation balance. The irrigated land in dry areas reduces albedo by 5 per cent in comparison to the surrounding desert areas.

(3) **At Global Level :** The radiation balance at **global level** is changed in the following manner : (i) Emission of carbon dioxide through the burning of hydrocarbon fuels(coal, petroleum, natural gas etc.) and its concentration in the atmosphere raises the temperature of the earth's surface by retarding the loss of heat from the ground surface through outgoing longwave terrestrial radiation, and (ii) The introduction of chlorofluorocarbon and nitrogen oxides in the stratosphere depletes ozone layer and thus allows more ultraviolet solar rays to reach the earth's surface. This results in the increase of incoming shortwave solar radiation which raises the temperature of the ground surface and the lower atmosphere. This in turn changes the heat balance of the earth and its atmosphere.

It may be pointed out that the effects of human activities in changing the radiation balance are so complex and involve negative feedback mechanisms that it is not easy to build any adequate model which can well explain the impact of human activities on radiation balance. Any change in radiation balance effected by man would certainly cause changes and alteration in other environmental processes because radiation balance is a key factor to weather and climate of the planet earth. Any change in the natural state of radiation balance may change the weather and climatic conditions from local through regional to global levels which in turn would affect the hydrological cycle and processes, flow of sediments and chemical elements in the biospheric ecosystem and food chains affecting all forms of life in the biosphere. The impact of depletion of ozone layer, incressing greenhouse effects and other factors on radiation balance, weather and climate will be discussed in the succeeding sections.

13.5 GLOBAL WARMING

The most significant global environmental problem faced by the world community is related to **global environmental changes** (GEC) consequent upon **global warming** resulting from a host of causal factors mainly anthropogenic factors such as changes in atmospheric chemistry, ozone depletion, emission of greenhouse gases at alarming increasing rate, urbanization, land use changes mainly deforestation etc. The probable net result of global warming and changes in atmospheric chemistry through air pollution and other natural sources would be **climatic changes** at local, regional and global levels including both short-term and long-term changes in weather and climate.

The international communities are scared of catastrophic adverse effects of future climatic changes on different spheres of man and nature e.g. deglaciation and sea level changes, submergence of island nations and major coastal lowlands, atmospehric dynamics including evaporation and precipitation, global radiation balance, photosynthesis and ecological productivity, plant and animal community, human health and wealth and many more. The major sources of global environmental problems have been identified as changes in atmospheric chemistry through air pollution (both gaseous and solid particulates pollution), through rapid rate of industrialization and urbanization, population growth at alarming rate, advances in productive technology, major land use changes mainly deforestation etc. and efforts are afoot for tackling the problem of global warming leading to climatic changes at international level.

It is thus, necessary to discuss the evidences of global warming, trend of global warming, processes of global warming including ozone dpletion and emission of greenhouse gases, effects of global warming, air pollution leading to changes in atmospheric chemistry, and related environmental problems and international cooperations to tackle the problems of global warming and climatic changes.

13.6 EVIDENCES OF GLOBAL WARMING

Global warming refers to gradual rise in atmospheric and ground surface air temperatures and consequent changes in global radiation balance caused mainly by anthropogenic processes (although natural processes also cause global warming and cooling) leading to climatic changes at different levels (e.g. local, regional and global levels). It may be pointed out that the pattern of global rise in air temperatures has been studied and reported by different scientists and agencies, and a few computer models have been constructed, but their results are not uniform, rather a few are contrasting. The **radiative forcing** and **global warming potential** (GWP) are used by the Inter-governmental Panel on Climate Change (IPCC) to compare the relative warming effect of different gases. The radiative forcing as defined by the IPCC refers to 'the effects which greenhouse gases have in altering the energy balance of the earth-atmosphere system'. On the other hand, the global warming potential is used as a tool to compare the relative warming effect of various gases emitted from anthropogenic sources such as carbon dioxide, carbon monoxide, nitrogen oxides, methane, sulphur dioxide, chlorofluorocarbon etc. (these will be discussed under the heading 'air pollution', in chapter 20, entitled **'environmental pollution'**).

The scientists have attempted to identify convincing evidences to demonstrate the rising trend of air temperatures at least since the beginning of industrial revolution (1860 A.D.), though systematic recording of temperatures at different meteorological centres in the world started since 1880 A.D. It may be mentioned that only those evidences may yield fruitful results in demonstrating any trend of rise in air temperatures (which is the only indicator of global warming) which are temperature-dependent evidences. The following evidences support the theory of gradual rise in air temperature and consequent global warming :

1. Temperature records,
2. Melting of mountain and continental glaciers,
3. Warming of ocean water at global level,
4. Rise in sea level,
5. Thawing of permafrost areas,
6. Upward shifting of snow lines of the tropical and subtropical mountains,
7. Spreading of tropical diseases towards temperate and polar regions,
8. Shifting of seasonal weather phenomena and changes in precipitation patterns etc.

Increase in Air Temperature

It has been stated that the overall increase in the air temperature in the 20th century has been about 0.5 to 0.7^{0}C. The last century i.e. the 20th century has been the warmest century in the last 2000 years. The last two decades of the 20th century (1980's and 1990's) have been warmest decades since the systematic recording of air temperature began in 1880. All the ten warmest years have occurred since 1980. The last decade of the 20th century (1990's) was the warmest single decade in the historical record of temperature, as seven out of ten warmest years occurred in this decade wherein the year 1998 was the warmest year of the millennium.

The 2001 **Synthesis Report** on Climate Change by **Intergovernmental Panel on Climate Change** (IPCC) has shown that if the concentration of atmospheric CO_2 increases to 540-970 ppmv by the end of the 21st century, the average global temperature may rise by 1.4 to 5.8^{0}C and sea level may rise to 9-88cm from 1990 level (table 13.5) if no serious attempts are made to check CO_2 concentration.

Table 13.5 : Projection of emission of CO_2 and consequent rise in average global temperature and sea level

Year	2025	2050	2100
CO_2 concentration	405-460 ppm	445-640 ppm	540-970 ppm
Global mean temperature change from the year 1990	0.4-1.1^{0}C	0.8-2.6^{0}C	1.4-5.8^{0}C
Global mean sea level rise from the year 1990	3-14cm	5-32cm	9-88cm

Source :IPCC synthesis report on climate change, 2001

The **World Wildlife Fund (WWF)** predicted in December, 2005 that 'the earth could warm by 2^{0}C above pre-industrial level as early as 2026 A.D. and by 6^{0}C in the Arctic region'.

The **IPCC Report, 2007** (Intergovernmental Panel on Climate Change) stated that the years 1998 and 2005 (also 2010) were warmest two years in the recorded global surface air temperature history since 1850. Eleven out of the last 12 years between 1995 to 2006 (the year 1996 was an exception) ranked among the 12 warmest years on record since 1850. The following are the salient features :

- The global surface temperature increased by 0.74^{0}C ± 0.180^{0}C between 1906-2005 while this 100-years increase was only 0.6^{0}C ± 0.2^{0}C between 1901-2000.
- The total temperature increase from 1850-1899 to 2001-2005 is 0.76^{0}C ± 0.19^{0}C.
- Different global estimates show consistent warming trends.
- The effects of urbanization and land use changes on global warming or global temperature record are negligible, that is less than 0.006^{0}C per decade over land areas and zero over ocean surface.
- Surface temperature over land regions have warmed at a faster rate than over the oceans in both the hemisphere.

2010, A Remarkable year

The year 2010 became a remarkable year in the annals of climatology due to following weather phenamena which occurred during this year :

- 2010 bacame the hottest year at par with the year 2005 since temperature recording began in 1880.
- 2010, 40 per cent rise in CO_2 level since industrial revolution.
- 2010, the wettest year in the historical records.
- 2010, record heavy snowfall in Europe and North America breaking all previous records.
- 2010. severe floods in Pakistan, Australia, California and Tennessee.
- 2010, severe coral bleaching and coral death.

2010, Indian Scenerio

- 2010, warmest year since 1901 in India.
- 2010, an increase of 0.93°C average temperature over 30 year period from 1961 to 1990.
- 2010, north and central India was warmer than rest of the country.
- 2010, mean temperature was 0.6°C above the mean temperature of 1901-1990.
- Out of 10 warmest years, 7 were recorded in the 1st decade of the 21st century (2001 to 2010).

Melting of Ice Sheets and Glaciers

The recent evidences have shown that the **ice sheets of Antarctica** and **Greenland** are breaking, the permanent ice covers of the arctic regions are melting, and continental and mountain glaciers are shrinking in both size and length as evidenced by their regular retreat. It may be mentioned that the Antarctica is well instrumented continent in terms of the study of various aspects of the continent e.g. surface and air temperatures, ice core analysis, size and thickness of ice sheets and glaciers, contraction and shrinking rate of ice sheets etc. The regular monitoring of Antarctic ice sheets has shown about 100 m annual rate of their shrinking. A rise of temperature of winter season by 4°C has been reported since 1950 in the west Antarcfic Peninsula. There are ample evidences to demonstrate regular breaking of ice shelves and formation of giant icebergs which are floating masses of ice. It may be mentioned that ice shelf is floating huge mass of ice but is attached to the landmass while icebergs are floating masses of ice independent of ice shelves. In other words, the icebergs are formed when the ice shelves are disintegrated, thus huge voluminous mass of ice known as iceberg measuring several hundred square kilometers in area, floats independently in the sea. It is significant to point out that melting of ice-bergs does not make any change in seal level because these have already occupied places in the sea but melting of ice shelves and glaciers causes rise in sea level. The disintegration of Antarctic ice shelves is rapidly increasing e.g. Larsen iceshelf disitegrated in 1995 while many Antarctic iceshelves including Larsen B and Wilkes iceshelves broke away during 1998-1999

The study of 244 glaciers in the Antarctic Peninsula since 1950 by the **British Antarctic Survey** based on 2000 aerial photographs taken since 1940s and more than 100 modern satellite images revealed the fact through its report published in 2005 that temperature in this region has registered a rise of 2°C since 1950, 87 per cent of 244 glaciers have shown significant shrinking in their size and length. The glaciers registered a much faster rate of retreat i.e. 50 m per year since 2000 A.D. The study further shows that the glaciers are losing 250 cubic kilometers of ice every year.

Recording of ice covers over **Bering Sea and Arctic Sea** has revealed gradual but regular shrinking of their areas, e.g. (i) there has been decrease in areal coverage of Bering sea ice covers by 5 per cent since 1960, (ii) the sea ice area over Arctic sea has decreased by about 90,000 square kilometers since 1978 etc.

The ice cover area of the Arctic Sea around North Pole registered a record shrinkage during 2005-06 as reported by Walt Meier, a researcher at the U.S. National Snow and Ice Data Center, Colorado in 2006. 'The Arctic is repidly becoming the clearest demonstration of the effects of mankinds' impact on the global climate. The temperature is rising twice as fast as the rest of the planet and the region is expected to warm by a further four degrees centrigrade to seven degrees centrigrade by 2100 A.D.' (Hindu, 2006). The scientists believe that if the present trend of melting of Arctic ice continues, the Arctic Sea will lose most of its ice by 2030 A.D.

There are ample evidences to demonstrate the melting and retreat of **mountain glaciers** i.e. Alpine, Himalayan and Andean glaciers etc. A few examples would be sufficient enough to validate the melting and retreat of mountain glaciers upward e.g. (i) European Alpine glaciers have been reported to have shrunk in their length and volume by more than 50 per cent in the past century, (ii) the rate of upward retreat of Andean glaciers in Peru increased seven times in the last 3 decades of the 20th century, more prescisely between 1978 and 2000 A.D., (iii) the Russian Caucases mountain glaciers have been shortened in their length by about 50 per cent due to melting since 1960, (iv) the glaciers of Chinese Tien Shan Mountains have lost their ice volume by 25 per cent on melting since 1960, (v) the glaciers of Southern Alps of New Zealand have moved upward by about 1000 meters due to their retreat caused by thermal melting of ice, (vi) Mt. Kenya has lost its most extensive glacier in the past century etc.

Different studies have demonstrated faster rate of melting of the **Himalayan glaciers** in India, resulting into their upward retreat and negative mass balance. A recent study of 19 glaciers of the Baspa basin of Himachal Pradesh by the scientists of Marine and Water Resource Group of Space Application Center (SAC), Ahmedabad during 2000-2002 on the basis of weekly satellite images and field data provided by the Geological Survey of India (GSI) has revealed that their mass balance during 2001 and 2002 registered negative trend (i.e. - $90m^3$ in 2001 and -$78m^3$ in 2002). The study revealed that if the current rate of retreat continues, these glaciers would disappear by 2040 A.D. The study by SAC scientists from 1962 to 2001 also revealed loss of 24 per cent of glacial ice cover at the altitude of 5000 meters and of 14 percent at the altitude of more than 5000 meters. The latest findings of SAC studies published in Current Science (Vol. 86, No 1, 2004) as reported in Down to Earth (March 31, 2004) revealed the fact that continuous melting and retreat of glaciers in Himachal Pradesh resulting into decrease in the mass of ice of glaciers would result in marked reduction on runoff causing serious shortage of water supply in future. The rapid rate of retreat of glaciers in the Garhwal and Kumaon Himalayas has also been reported.

According to the latest survey of the Himalaya by Chinese scientists there is reduction in the height of Himalaya since 1966. The measured height of Mt. Evertest was 8849.75 meters in 1966 which dropped to 8848.45m in 1999, thus registering a drop of 1.3 m height in 33 years. The rate of lowering of its height was 0.1 m per year from 1966 to 1975, 0.01 m between 1975 and 1992 and again 0.1m from 1992 to 1999.

Melting of Permafrost

It has been demonstrated by a few scientists that a large amount of carbon is stored in the soils. David Lawrence, a climate scientist associated with the U.S. National Center for Atmospheric Research has studied the nature of melting of Arctic permafrost. His studies (2005) have revealed the fact that the upper layer of the Arctic permafrost holds about 30 per cent of the total carbon held by the soils world over. The global warming, if unchecked, would cause the melting of the Arctic permafrost resulting into the thawing of 1.5 million square miles of permafrost area upto the depth of 3.5m by 2100 A.D. This would release immense volume of carbon to the atmosphere which would further intensify greenhouse effect and would accelerate the process of global warming resulting into dramatic climate changes.

Other Indicators

- The gradual spread of a few tropical and subtropical diseases poleward such as malaria, cholera, plague, dengu fever, yellow fever etc. is indicative of global warming. It may be mentioned that the insects, bacteria, virsuses of such diseases flourish in extreme weather conditions e.g. extreme heat and cold, and extreme wet and dry seasons. The global warming is supposed to bring extreme weather conditions in the middle and high latitudes. The cases of outbreaks of cholera (in 1991 in Peru), dengue fever (e.g. during 1994 in Australia) and malaria in the temperate countries demonstrate the warming of middle latitude areas. According to an estimate, presently tropical diseases cover about 42 per cent area of the globe which may increase to 60 per cent if the earth's surface average temperature rises by 2^{0}C.
- **Decrease in the Antarctic penguins population** by 40 per cent during the past 3 decades of the 20th century, due to their deaths from starvation because rise in sea temperature causes marked decrease in zooplanktons which are main sources of penguine feeding, is indicative of global warming.
- Mass destruction of corals due to **coral bleaching** is another significant indicator of global warming. The coral bleaching during 1997-98 has been recorded as the most catastrophic event as it accounted for large-scale deaths of corals in the tropical oceans of 60 countries and island nations. Though coral bleaching was observed by Alfred Mayer as back as 1991 but it was the year 1998 when large-scale coral bleaching accounting for 70 per cent deaths of corals off the coast of Kenya, Maldives, Andman and Lakshadeep islands in the Indian Ocean and 75 per cent deaths in the Seychelles Marine Park System and the Mafia Marine Park of Tanzania was reported by Clive Wilkinson of the Global Coral Reef Monitoring Network (GCRMN) of Townsville (Australia). The coral bleaching is related to 2^{0}C rise in temperature from the normal temperature in the Andman Sea in 1997-98.
- The analysis of recorded temperatures at the sea surface and below upto the depths ranging between 800 meters and 3000 meters has revealed the fact that the **average sea temperature** has risen by 0.6^{0}C in the later half of the 20th century which caused rise in sea level by 10-25 centimeters. It has been estimated that if the current rae of increase of sea temperature continues upto the end of the present century i.e. by 2100 years, the sea level would register an increase of one meter.

The **continued thawing of permafrost areas** in Alaska and Siberia is another testimony of global warming. The studies by various scientists have indicated rise of temperatures of the upper layer (active layer) of permafrost ranging between 0.6^{0}C and 1.5^{0}C in Alaska resulting into the thawing of the upper layer of permafrost.

- **Expansion in the area and latitudinal extent of the tropics** is a convincing evidence of global warming. The measurements of atmospheric temperature by the U.S. weather satellites have revealed the fact the tropical zone has expanded by 2^0 latitude or by 224 km on either side of the equator since 1979. This observation is based on the data of temperatures from 1979 to 2005 by TIROS-N and NOAA weather satellites. The **poleward shift of jet streams** is also an indicator of global warming.
- Increase in the annual frequency and severity of tropical storms also indicates global warming. The all time record of 19 storms in the USA during 1969 was broken in the year 2005 when 27 hurricanes, including Katrina and Wilma struck USA.

13.7 PROCESSES OF GLOBAL WARMING

Major sources and processes of global warming include ozone depletion and greenhose effects.

Thus, it is necessary to understand the mechanism of creation, destruction and maintenance of ozone layer and sources and processes of intensification of greenhouse effects by increasing emission of carbon dioxide and methane for evalution of global warming.

13.8 OZONE DEPLETION

The mechanism of ozone depletion includes the aspects of creation of ozone, destruction of ozone and recreation or maintenance of ozone layer in the stratosphere. It is desirable to understand the mechanism of formation of ozone layer first so that the processes of its destruciton and its impacts on global warming can be properly understood. It may be mentioned that the thinning of stratospheric ozone layer allows more ultraviolet solar radiation to reach the earth's surface and thereby increases the temperature of the earth's surface.

The stratospheric ozone layer mostly concentrated between the altitudes of 12km to 35km, is considered as a protective shield and earth's umbrella because it prevents ultraviolet solar radiation from reaching the earth's surface. Thus, the presence of ozone layer in the stratosphere is of vital significance for all biota including plants, animals and man in the biosphere. In the absence of this layer no life is possible in the biosphere because ~~all~~ the ultraviolet rays of the sun will reach the earth's surface and consequently the temperature of the earth's surface and the lower atmosphere will rise to such an extent that the **'biological' furnace'** of the biosphere will turn into a **'blast furnace'**. It is, thus, desirable to study the various aspects of this invaluable ozone layer viz. the formation of ozone layer, global concern of its depletion, factors and mechanisms of its depletion, effects of ozone depletion and maintenance of ozone layer.

1. Creation of Ozone Layer

Ozone, defined as 'a three-atom isotope (one of a set of chemically identical species of atoms which have the same atomic number but different atomic weight is called isotope) of oxygen (O_3)', or 'merely a triatomic form of oxygen (O_3), is a faintly blue irritating gas with a characterstic pungent odour. Ozone is a strong oxidizing agent which can at high oncentrations decompose with an explosion'. There are contrasting opinions about the altitudes of the concentration of ozone. It may be pointed out that ozone is present almost at all altitudes in the atmosphere but the bulk of its concentration is present in a layer from 10 km to 50 km up in the atmosphere and within this ozone the highest concentration of ozone is between the altitudes of 12 km and 35km in the **stratosphere**. This zone (12km-35m) of ozone is called **ozonosphere** or **ozone layer** or **stratospheric ozone layer.**

The ozone gas is unstable because it is created as well as destroyed or disintegrated. In other words, the creation and destruction of ozone gas is a gradual and continuous natural process. The oxygen molecules are broken up or separated in the atmospheric layer between the altitudes of 80 to 100 km by ultraviolet solar radiation or by an electric discharge in oxygen or air during a thunderstorm in the troposphere in the following manner :

$$O_2 \rightarrow O + O$$

(Oxygen breaks up into two separate oxygen molecules)

~~These separated oxygen~~ atoms (O) are then combined with oxygen molecules (O_2) and thus ozone (O_3) is formed.

$$O_2 + O + M \rightarrow O_3 + M$$

Or

$O_2 + O$..........................O_3 (ozone)

Where M denotes energy and momentum balance produced by the collision of oxygen molecules (O_2) with another individual atom or molecule. It may be pointed out that the collisions of 3 atmos or molecules or the collisions of oxygen (O_2) with the third atom are not vey common feature of regular occurrence between the altitdues of 80 to 100 km (though O_2 is very frequently broken up into individual atom or molecule in this layer as referred to above) because of very low density of gases in this part of the atmosphere and such collisions are also very rare in the atmosphere below the altitude of 35 km because most of the solar ultraviolet rays have already been absorbed above this height. Thus it is obvious that the formation of ozone (O_3) due to collision of 3 atoms ($O_2 + O$) through th process of **photomechanical reaction** triggered by the sunlight is more active in the atmospheric zone of 30 to 60 km height from the sea level. It is further important to note that the **ozone mixing ratio** (ozone mixing ratio = mass of ozone per unit mass of dry air) is maximum at the height of about 35 km but the maximum **ozone density** (ozone density = mass of ozone per unit volume) is found between the height of 20 km to 25 km. This is because of the fact that ozone is transported to lower height (upto 12 km) by some upper air atmospheric circulation mechanisms which allow the ozone gas to accumulate between the height of 12 km to 35 km.

It is also important to note that most of the stratospheric ozone is formed in the atmosphere over the tropical areas from where some ozone is transported by the atmospheric circulation to the polar areas up in the atmosphere. The ozone (O_3) is also transformed back into oxygen by further collision of ozone with monatomic oxygen (individual molecule of oxygen, O) in the following manner.

Ozone (O_3) + O → Oxygen (O_2) + Oxygen (O_2)

Ozone is also transformed into oxygen by **photochemical processes** (by the actions of solar radiation on ozone).

In a very simpler term the process of the formation of ozone may be described as the production of ozone by the actions of ultraviolet rays on ordinary oxygen atoms by the photochemical process which is responsible for the constant transformation of oxygen (through the collision of 3 atoms of oxygen i.e. $O_2 + O$) to ozone and from ozone back to oxygen. Thus the constant formation or production and destruction of ozone is a natural process which maintains an approximate equilibrium level of ozone in the atmosphere if not interfered by human activities.

Though ozone layer contributes only about 3 to 4 mm of thickness to the total atmospheric thickness of 8m (if the whole of atmosphere may be compressed to sea level temperature and pressure) but this layer is a life-saving protective cover for all the biota of the biosphere.

2. Depletion of Ozone Layer : An Environmental Concern

There has been much hue and cry about the depletion of stratospheric ozone in the last one or two decades (of the 20th century) and the issue now has assumed a global dimension because the problem of ozone depletion and its adverse conssequences have threatened the existence of all forms of life in the biosphere. The presence of ozone layer in the atmosphere is very crucial and significant for plants and animals in general and human beings in particular because it provides a protective cover, known as earth's umbrella, to all of the organisms (including plants, animals, micro-organisms and man) in the biospheric ecosystem against their exposure to ultraviolet solar radiation by absorbing unwanted ultraviolet rays and allowiing only those radiation waves to reach the earth's surface which are essential for the maintenance of life on the planet earth. Any change in the equilibrium level of zone in the atmosphere will adversely affect the life in the biosphere. Thus, the growing concern for the depletion of stratospheric ozone is not without reason and scientific evidences. The following evidences and effors of scientific communities and governments are sufficient enough to demonstrate the growing awareness about the importance of ozone and possible adverse effects arising out of its sharp depletion.

Perhaps the first concious effort to sound a warning about the depletion of ozone layer was made in the Western World by M. Molina and S. Rowland of the University of California (U.S.A.) in 1974-75 when the result of their published theoretical computer studies using a unidimensional linear model predicted the accumulation of man-made ozone destroyer chemicals known as chlorofluorocarbons in the atmosphere of the earth and rapid rate of depletion of ozone because of the presence of these chemicals. On the other hand, the efforts to collect information and data of the variations in the ozone level in earth's atmosphere based on satellite monitoring on regular basis started in Russia as back as 1967. The data of ozone level variations coming through satellite monitoring since 1967 have revealed sharp depletion of ozone layer. The monitoring from NIMBUS 3, NIMBUS 4 satellites and EXPLORER 5 and TYROS 4 of the former U.S.S.R. indicated definite variations in the ozone level. The sharp decline in the ozone level during 1960's was attributed to the discharge and transport of nitrous oxides caused by numerous nuclear tests carried out by the developed nations like Russia, the U.S.A., France etc. into the atmosphere. The original level of ozone was restored and the depleted ozone layer was gradually stabilized soon after the banning of nuclear tests in the atmosphere.

The British Antarctic Survey Team led by Josepth Farman provided first hand evidence of ozone depletion over the Antartica in 1985. Joseph Farman reported 40 per cent loss in the spring time ozone layer in the atmosphere lying over Antarctica (reported in Nature, 1985).

Ozone Hole

Following the startling findings of ozone depletion over Antarctica by the British team (3 British scientists, Joseph Farman, Brian Gardiner and Jonathan Shanklin, first of all discovered ozone hole over Antarctica in 1985) a Multinational Expedition was launched during the spring season (March to October) of 1987. This expedition nvolviing scientists from several countries conducted satellite, aircraft, baloon and terrestrial measurements to find out the level of ozone in the atmosphere over Antarctica involving an area twice as large as the U.S.A. The findings of this multinatinoal expedition team revealed that (i) the average natural concentration of ozone dropped by 50 per cent between August, 15 (1987) to October, 7, 1987, and (ii) in some patches of the observed area the ozone concentration dropped by 100 per cent or ozone totally disappeared which resulted into the formation of ozoneless patches now called as **ozone hole** in the ozone layer or the **ozonosphere.**

Thus following the startling revelations by the British Antarctic Survey Team in 1985 and the Multinational Expedition of Antarctica in 1987 about the depletion of ozone layer and the creation of **ozone hole** over Antarctica the **Montreal Protocal** on substances that deplete the zone layer was signed in September 1987 by 35 countries. This first international agreement to limit the production and consumption of ozone depleting chemicals such as CFC (chlorofluorocarbon) was made possible due to sincere efforts made by the developed countries and leading scientists under the United Nations Environmet Programme (UNEP).

The World Watch Institute (U.S.A.) released the first authentic and well documented detailed research monograph on the threat to the ozone layer authored by Cynthia Pollock Shea in 1988. It may be pointed out that prior to the release of the report of the NASA Ozone Trend Panel in 1988 there was a common belief that the depletion of ozone was a seasonal phenomenon and was confined to the atmosphere lying over Antarctica alone but the report of the said NASA OTP (NASA Ozone Trend Panel) based on the conclusions of more than 100 scientists of 10 countries revealed that the previous orthodox hypothesis of ozone depletion only over Antarctica was erroneous and therefore not tenable and concluded that the depletion of ozone layer was a global affair.

The **World Watch Institute** further released a detaield report on the **State of the World** in 1989 wherein several crucial factors responsible for environmetnal degradation such as the depletion of ozone layer, greenhouse effects, soil erosion, deforestation and population growth were listed and detailed immediate action plans at global scale were suggested inorder to safeguard the earth from the perilous effects of these man-made environmental diseases so that the future generations might not curse the present human society.

A three-day international conference involving a large number of ministers, senior officials, leading international scientific societies, scientists and industrialists of over 150 countries was organised between March 5 to 7, 1989, at London at the behest of the United Nations Organisation. The central theme of the conference was to search ways and means to save the endangered ozone layer. The basic issues were concerned with limiting the production and consumption of ozone depleting chemicals such as chlorofluorocarbons not only in the developed countries but also in the developing countries. The deleberations and decisions of the London Conference on 'Save Ozone Layer' as referred to above will be discussed in the next subsection of this topic (maintenance of ozone layer).

Ozone Halo

Contrary to ozone depletion ozone halo refers to concentration of excess ozone around a low ozone zone above a specific location. The study conducted by the department of chemical and physical sciences at the University of Toronto, Canada has reported the concentration of excess ozone around the Tibetan Plateau. G.W. Kent Moore found, in January, 2005, a concentrated ring of excess ozone at the height of 4000 m around the Tibetan plateau as revealed by satellite measurements. This ring of excess ozone existed from October-November, 1997 to 2004 but the central parts over the Tibetan Plateau showed low levels of ozone. According to Moore the ozone halo is formed due to the plateau acting as an obstacle which creates a column of stagnant air above the plateau. 'The ozone ring was probably formed because the plateau's influence extends into the ozone-rich upper troposphere and the lower stratosphere' (Down to Earth's Jan. 15, 2006).

3. Factors and Mechanisms of Ozone Depletion and Creation of Ozone Hole

The mechanisms of ozone depletion include both (i) the **natural processes,** and (ii) the **anthropogenic processes.**

(i) The **natural processes** of ozone depletion involve the conversion of atmospheric nitrogen into nitrous oxides due to solar activity because of maximum sunspots at the end of every 11-year cycle. According to latest estimate the level of nitrous oxides rises from 30 to 60 per cent at the end of 11-year cycle in the middle latitudes of the southern hemisphere. This mass of nitrous oxides is transported to the stratosphere over the polar areas during winter season (polar night). These nitrous oxides then deplete the ozone layer through photochemical reacitons. These nitrous oxides also augment the rate of ozone depletion triggered by chlorine molecules. Secondly, ozone (O_3) is also split into oxygen (O_2) and single oxygen molecule because of ultraviolet solar radiation. The natural mechanisms of ozone depletion do not necessarily upset the ozone equilibrium in the atmosphere because the loss of ozone caused by natural processes is suitably compensated by the creation of ozone through natural processes. Thirdly, the dynamic mechanism involves the redistribution of ozone by the atmospheric circulation. It has been suggested that the upper air atmospheric circulation transports ozone from over south pole and accumulates it in a belt between 60^0 to 70^0S. This transport of ozone from over south pole results in the thinning of ozone layer and thus the formation of ozone hole.

(ii) The **anthropogenic mechanisms** of ozone depletion include a few processes on which the following hypotheses have been postulated :

(1) chlorine hypothesis,

(2) sulphate hypothesis,

(3) nitrogen oxides hypothesis, and

(4) polar stratospheric clouds hypothesis,

(1) Chlorine Hypothesis

The chloro-fluorocarbon and halon gases are released during the maintenance or operation of seveal devices using these synthetic chemicals (such as refrigerators, airconditioners, spray-can dispensers etc.) shredding of foam insulation and fire fighting into the atmosphere. Initially, these gases are chemically inert and nontoxic at the ground level and in the troposphere. These gases also do not break down in the troposphere. These are transported upward into the stratosphere. The transport of chlorofluorocarbons and halons by vertical atmospheric circulations to the stratosphere normally takes 6 to 8 years or even more (about 10 years). These gases are further transported to the south polar stratosphere. The depletion of ozone due to chlorofluorocarbons and halons involves the following steps :

- A swirling polar vortex is formed over the south pole (in the atmosphere) during long Antarctic winter (from March to September).
- This swirling south polar Antarctic vortex causes considerable lowering of temperature.
- The meagre amount of vapour present in the dry upper atmosphere is frozen due to markedly low temperature below freezing ponit. This frozen upper atmospheric moisture forms upper atmospheric or stratospheric clouds.
- The chlorine and bromine of chlorofluorocarbons and halons are converted from their initial non-reactive form to reactive form because of the chemical reactions on the ice crystals. It may be mentioned that chlorofluorocarbons and halons are transported to the stratosphere by vertical atmospheric circulation. Thus the transformed form of non-reactive chlorine and bromine, as reactive molecules, becomes very much sensitive to sunlight.
- The nitrogen oxides generally inactivate chlorine but the lowering of stratospheric temperature because of polar Antarctic swirling vortex transforms nitrogen oxides into frozen form which then becomes non-reactive nitric acid.
- During the next spring sunlight breaks down chlorofluorocarbons and halons through the mechanism of photochemical processes and thus chlorine and bromine are released to the atmosphere. These halogen molecules then disintegrate ozone (O_3) into ordinary oxygen ($O_2 + O$) and thus the process of destruction or depletion of ozone starts.

(2) Sulphate Hypothesis

In 1986 it was established by the scientists that the chemistry of cloud surface is of paramount significance in the destruction of ozone. It is believed that the sulphate aerosols emitted through volcanic eruptions (natural) and numerous constantly active human volcanoes (chimneys of factories) accumulate in the atmosphere at all latitudes between the altitudes of 15 km to 22 km. It has been discovered that the concentration of sulphate aerosols is most prevalent over the populated and industrialised areas of the northern hemisphere. This trend further validates the belief that most of the sulphate aerosols present in the atmosphere are contributed by human (industrial) activities. These sulphate aerosols catalyse the transformation of ozone to ordinary oxygen (O_2+O). If this **sulphate hypothesis** of ozone depletion is accepted, the destruction of the ozone layer thus becomes global phenomenon and the depletion of ozone would be accelerated more than anticipated on the basis of **chlorine hypothesis** (depletion of ozone due to chlorine molecules released from the breakdown of chlorofluorocarbon).

(3) Nitrogen Oxides Hypothesis

The nitrogen oxides hypothesis states that nitrogen oxides emitted from supersonic jets in the higher altitudes deplete ozone. The supersonic transport aircrafts (SST) flying at the speed of more than twice the speed of sound at altitude of 18 to 20 km release significant amount of nitrogen oxides from their exhausts (the first commercial flights of Concorde and Super Sonic Transport aircrafts started on January 22, 1976). The study of impact of nitrogen oxides released from the exhausts of a large fleet of Super Sonic Transport (SST) aircrafts on the stratospheric ozone conducted by Harold H. Johnston, an atmospheric scientist at the University of California, Berkeley (U.S.A.) demonstrated that 'a fleet of 500 Boeing SSTs would reduce global ozone by a value between 3 and 23% over all the earth's surface, and by as much as 50% near areas of intensive air travel' (A.N. Strahler and A.H. Strahler, 1976). The **Climatic Impact Assessment Programme** (CIAP) launched by the U.S. Department of Transportation (DoT) to study the impact of nitrogen oxides on ozone depletion confirmed the initial conclusion of considerable impact of nitrogen oxides released from the exhausts of Super Sonic Transport aircrafts on ozone as drawn by H.H. Johnston as referred to above. Further studies to assess the impact of nitrogen oxides on stratospheric ozone conducted by the U.S. National Academy of Sciences and the U.S. National Academy of Engineering have confirmed the potential impact of nitrogen oxides of ozone depletion.

(4) Polar Stratospheric Clouds Hypothesis

The research team of the Cambridge University, U.K. reported in march, 2005 that the concentration of stratospheric ozone over Arctic region decreased upto 50 per cent between November, 2004 to March, 2005. According to Markus Rex of the Alfred Wegener Institute, located in Potsdam, Germany, the Arctic ozone layer was depleted upto 30 per cent by 2005. The question arises, as to why the ozone layer got depleted over the Arctic region inspite of substantial reduction in the production and consumptin of CFCs under Montreal Protocol? It may be mentioned that the depletion of ozone layer continues though there is gradual decrease in the production and consumption of ozone depleting substances. It means that besides CFCs being major factor of ozone depletion, there are also other factors which contribute in the depletion of stratospheric ozone layer. According to John Pyle (2005) of the research team of the Cambridge University there has been maximum depletion of Arctic stratospheric ozone between 1965 and 2005. It was believed by the scientists that after the implementation of Montreal Protocol there would be substantial decrease in ozone depletion but this could not happen. Now the scientists believe that the increase in the number of clouds in the Arctic stratosphere leads to reduction in the concentration of stratospheric ozone. The green house effect causes warming of lower atmosphere but there is cooling of stratosphere. This phenomenon causes formation of ice clouds at the height of 14-26 km in the stratosphere. It may be remembered that there is also maximum concentration of ozone within this zone of the atmospehre. There are fast chemical reactions due to such ice clouds in ozone zone which cause depletion of ozone layer. According to Markus Rex the cloud covers in the stratosphere over the Arctic region increased four times in 2005 in comparison to Arctic stratospheric cloud covers during the decades 1960 and 1970 due to marked cooling of the stratosphere. This led to record depletion of Arctic ozone layer upto the tune of 50 per cent during 2004-2005.

4. Ozone Depletion and Global Warming

According to one school of thought the net effect of ozone depletion mainly because of the impact of chlorofluorocarbons on thermal conditions of the earth's surface and the lower atmosphere would be highly complicated and unpredictable because of two facts arising out of ozone depletion viz. (i) Because of weakening of ozone layer there will be less absorption of ultraviolet solar radiation and hence more ultraviolet rays will reach the earth's surface and consequently the temperature of the earh's surface will be increased. (ii) On the other hand, the heating of the stratosphere will be reduced because of reduced absorption of ultraviolet rays. This phenomenon would result in the cooling of the earth's surface because of less thermal radiation from the stratosphere to the earth's surface. These two factors will certainly complicate the effects of ozone depletion due to the effects of chlorofluorocarbons. This hypothesis is not tenable because without doubt it has now been established that ozone depletion would result in the increase of surface temperature of the earth and its lower atmosphere.

It is believed that the depletion of ozone layer would result in 5 to 20 per cent more ultraviolet radiation reaching the populated areas of the world. The substantial increase in the surface temperature of the earth would cause global warming and climate changes at regional and global levels. The overall warming of the environment would cause melting of continental glaciers and ice sheets such as those of Antarctica and Greenland. This would in turn cause rise in sea level and consequent submergence of coastal lowlands.

Chlorofluoromethanes, besides depleting ozone layer, are also supposed to enhance the greenhouse effect of carbon dioxide because these halogen gases are effective absorbers in the 8-13 microns wavelength band but water vapour and carbon dioxide may not effectively absorb these radiation waves. Thus, the increased temperature would induce several climatic changes in various parts of the globe. It is also believed that the depletion of ozone in the stratosphere would result in the increase of the amount of hydrogen peroxide in the troposphere which would ultimately induce **acid rain.** Ozone depletion and increased ultraviolet solar radiation would also increase photochemical processes which in turn would create poisonous **urban smogs.**

5. Protection and Maintenance of Ozone Layer

The depletion of ozone layer and consequent imminent danger to biological communities in general and human society in particular have become a matter of serious environmental concern to governments, scientific communities and general public at local, regional and global levels. With the result serious attempts are being made at international level to heal the already wounded stratosphere by protecting and maintaining the precious ozone layer. The signing of Montreal Protocol in 1987 to reduce the production and consumption of chlorofluorocarbons and the organization of International Conference known as London Conference hosted by the British Government and collaborated by the United Nations Environment Programme (UNEP) during March 5-7 1989 at London to study the level and causes of ozone depletion and to involve more international participation to tackle the problem of ozone depletion clearly indicate the level of the seriousness of the problem and keenness of the world communities to protect the gradually depleting precious ozone layer. The remedial measures of ozone depletion at international level are being taken at two levels viz.

- to promote reduction in the production and consumption emissions of ozone depleting chemicals, and
- to make serious efforts to produce and propagate the use of alternative chemicals which do not deplete ozone in the stratosphere.

(i) **Reduction in the production and consumption of CFCs and halons :** The first and foremost task before the world cmmmunities is to stop or markedly reduce the production and consumption of ozone depleting synthetic chemical compounds like CFCs (chlorofluorocarbons) and halons. The Montreal Protocol signed in September 1987 at Montreal, Canada, by 35 developed countries of the world is the first concrete step in this regard. The signing of this Montreal Protocol was made possible because of continued efforts and negotiations made by the United Nations Environment Programme (UNEP). The following provisions were commonly agreed by the countries which signed the said protocol.

- To freeze the production of CFCs (chlorofluorocarbons) at 1986 level by 1989.
- To decrease the production of these synthetic chemical compounds by 20 per cent by the end of 1993.
- To allow further 30 per cent cut in the production of these chemicals by 1998.

➤ To freeze the produciton of halons at 1986 level starting from 1992.

➤ Thus the total production of ozone depleting chemicals (mainly CFCs and halons) would be reduced, according to the Montreal Protocol, by 50 per cent by the beginning of 1999 but this could not be achieved.

(ii) **Search for alternative technology** : Besides reducing the level of production and consumption of ozone depleting CFCs and halon, attentions are focussed on improving the use and maintenance of existing CFCs and halon and on searching substitute chemicals which can replace dangerous CFCs and halons. New techniques should be developed so that leakage of these gases may be stopped and efficient equipments may be used to handle these gases. A few substitute chemicals claimed to be chlorine free have been developed. For example, a U.S. based petroleum company has developed Bioact EC-7, a biodegradable non-toxic, and non-corrosive chemical known as HFC-134 (a trade name) which may be used in place of Freon-12 in airconditioners and refrigerators. This chemical is claimed to be free from chlorine. A new chemical called CFC-22 has been developed in the U.SA. as a substitute for Freon-11 and Freon-12. But the researches on the use and effects of CFC-22 conducted by the U.S. scientists have revealed that the CFC-22, a monochlorofluoromethane considered to be best among the fluurocarbons, also depletes ozone more than CFC-11 (Freon-11) and CFC-12 (Freon-12). The research laboratories of some companies have discovered that HCFs or CFCs with an added extra hydrogen atom may be used in airconditioners. Attempts are also being made in the developed and the industrialized countries to search for chlorine free substances that do not have ozone depletion potential but can be used in refrigerators.

6. Effects of Ozone Depletion

The most important function of the stratospheric ozone is to protect the troposphere and the earth's surface from most of the ultraviolet solar radiation by absorbing ultriviolet rays. Thus the ozone layer serves as an umbrella or shield against the ultraviolet solar radiation and saves the earth's surface from becoming too hot. The most dangerous effect of ozone depletion (ozone depletion means thinning of the ozone layer through lowering of its density in the stratosphere) would be substantial increase in the ultraviolet solar radiation reaching the earth's surface. The increased ultraviolet solar radiation in turn would raise the temperature of the earth's surface and the lower atmospehre. This would trigger a chain of effects and countereffects which would adversely affect the life-forms in the biosphere in a variety of ways.

(1) Effects on Climate

According to one school of thought the net effect of ozone depletion mainly because of the impact of chlorofluorocarbons on thermal conditions of the earth's surface and the lower atmosphere would be highly complicated and unpredictable because of two facts arising out of ozone depeltion viz. (i) Because of weakening of ozone layer there will be less absorption of ultraviolet solar radiation and hence more ultraviolet rays will reach the earth's surface and consequently the temperature of the earth's surface will increase. (ii) On the other hand, the heating of the stratosphere will be reduced because of reduced absorption of ultraviolet rays. This phenomenon would result in coolding of the earth's surface because of less thermal radiation from the stratosphere to the earth's surface. These two factors will certainly complicate the effects of ozone depletion due to the effects of chlorofluorocarbons. This hypothesis is not tenable because without doubt it has now been established that ozone depletion would result in the increase of surface temperature of the earth and its lower atmosphere.

It is believed that the depletion of ozone layer would result in 5 to 20 per cent more ultraviolet radiation reaching the populated areas of the world. The substantial increase in the surface temperature of the earth would cause global warming and climate changes at regional and global levels. The overall warming of the environment would cause melting of continental glaciers and ice sheets such as those of Antarctica and Greenland. This would in turn cause rise in sea level and consequent submergence of coastal lowlands.

Chlorofluoromethanes besides depleting ozone layer are also supposed to enhance the greenhosue effect of carbon dioxide because these halogen gases are effective absorbers in the 8-13 microns wavelength band but water vapour and carbon dioxide may not effectively absorb these radiation waves. Thus, the increased temperature would induce several climatic changes in varous parts of the globe. It is also believed that the depletion of ozone in the stratosphere would result in the increase of the amount of hydrogen peroxide in the troposphere which would ultimately induce **acid rain.** Ozone depletion and increased ultriviolet solar radiation would also increase photochemical processes which in turn would create poisonous urban smogs.

(2) Effects on Human Beings

The increased surface temperature because of more ultraviolet solar radiation reaching the earth's surface consequent upon ozone depletion would cause skin cancer particularly among the white populations. According to an estimate 12 per cent decrease in ozone because of nitrogen oxides emitted from the exhausts of a fleet of 500 Boeing Super Sonic Transport aircrafts would cause skin cancer to 1,20,000 people per year in the U.S.A. alone. Secondly, increased exposure of human bodies to ultraviolet solar radiation would decrease immunity of human bodies against infectious diseases with the result human beings would be more prone to infectious diseases. Further rise in temperature in the already hot and moist equatorial regions would further retard physiological growth of human bodies and would cause further supression of mental development of human beings. The resultant smog due to increased photochemical processes consequent upon more ultraviolet rays passing through the troposphere would adversely affect the respiratory system of human body. Smog impairs lung functions and reduces body strength to fight bacterial infections. Besides these diseases, human beings will face food shortage because of very severe adverse effects of increased ultraviolet solar radiation on agricultural crops, vegetation communities and fishes in the freshwater and marine aquatic ecosystems.

(3) Ecological Effects

The increased ultraviolet solar radiation would adversely affect plant and animal communities in a variety of ways. It is expected that photosynthesis, water use efficiency and yield of plants would be markedly decreased. The heavily fertilized crops would be more adversely affected due to their exposure to ultraviolet radiation. It is significant to point out that as the level of phosphorous in the soils increases, the plant resistivity to ultraviolet radiation decreases and hence plants are damaged. Due to rise in temperature consequent upon increased ultraviolet radiation the evaporation rate of surface water and soil moisture would be greatly accelerated resulting into phenomenal decrease in soil-moisture content. This would cause drying of agricultural crops and hence marked reduction in average and total crop production.

The photosynthesis by phytoplanktons in the marine ecosystem would be markedly reduced. Many micro-phytoplanktons would die because of their exposure to ultraviolet solar radiation. Thus, marked reduction in the productivity of phytoplanktons would in turn adversely affect zooplanktons and marine fishes because these will starve and die in the absence of sufficient supply of their food in the form of phytoplanktons.

The loss of fish population would directly affect human being because fishes are major source of food to the inhabitants of the coastal areas. The increased ultraviolet solar radiation will also increase the mortality rate of larvae of zooplanktons. It is also feared that the increased ultraviolet solar radiation may change the species composition of the marine ecosystems because of the fact that not all the marine species are uniformly vulnerable to ultraviolet solar radiation rather some species are more vulnerable while the others are less vulnerable to ultraviolet radiation.

The depletion of ozone, if not checked and corrected, would enormously change the global radiation and heat balance which is so dear to biological communities of the biopshere. In fact, any alteration in the global radiation balance may adversely affect the ecosystem productivity, ecological stability and overall environmental equilibrium. The depletion in ozone would trigger a number of changes in the biospheric ecosystem which would adversely affect the biological communities including man viz. (i) Ozone depletion will change the spectral composition of solar electromagnetic radiation reaching the earth's surface as more ultraviolet rays will reach the earth's surface. (ii) The increased solar ultraviolet radiation will increase surface temperature and thus will change the global energy and radiation balance. (iii) Increase in temperature may change climates at local, regional and global levels. Thus the resultant climatic changes would certainly change the physiological characteristics of animal bodies in general and human bodies in particular. (iv) Increase in temperature may decrease photosynthesis which in turn would reduce ecosystem productivity. (v) Change in radiation and energy balance would affect the survival and stability of living orgnisms. (vi) Increase in temperature due to increased ultraviolet solar radiation would affect precipitation (both increase and decrease depending upon the existing local environmental conditions) which in turn would affect water cycle which would ultimately affect broader biogeochemical cycles. (viii) The changes in thermal conditons of the earth's surface and the lower atmosphere would affect type, density and stability of vegetation which in turn would affect sediment and chemical elemetns cycles. All these changes consequent upon the depletion of ozone layer would upset ecological balance of the biosopheric ecosystem.

Coral Bleaching

Coral bleaching refers to loss of algae from the corals resulting into white colour which is indicative of death of corals. Global warming caused by ozone depletion and emissions of greenhosue gases has been reported as the major factor of coral bleaching. The coral bleaching during 1997-98 has been recorded as the most catastrophic event as it accounted for large-scale death of corals in the tropical oceans of 60 countries and island nations. Though coral bleaching was observed by Alfred Mayer as back as 1919 but it was the year 1998 when large scale coral bleaching acounting for 70 per cent death of corals off the coasts of Kenya, Maldives, Andamans and Lakshwadweep islands in the Indian Ocean and 75 per cent death in the Seychelles Marine Park System and the Mafia Marine Park of Tanzania was reported by Clive Wilkinson of the Global Coral Reef Monitoring Network (GCRMN) of Townsvile (Australia). He identified four overlapping levels of coral bleaching : (1) **catastrophic bleaching** adversely affecting 95 per cent of shallow water corals in Bahrain, the Maldives, Sri Lanka, Singapore and Tanzania; (2) **severe bleaching** accounting for 50-70 per cent death of corals in Kenya, Seychelles, Japan, Thailand and Vietnam; (3) **moderate bleaching** resulting into 20-50 per cent coral mortality but with quick recovery, and (4) **insignificant bleaching** or no bleaching.

The cases of large-scale bleaching have been reported in the Andaman and Nicobar islands of India. It may be pointed out that the areal coverage of coral reefs in India has been estimated to be 18,000 km^2. The corals have mainly colonized around the Lakshwadeep and the Andman and Nicobar islands. Besides, small patches of coral reefs are found in the Gulf of Kutch and the Gulf of Manar. According to the study conducted by the

Society for Andman and Nicobar Ecology (SANE) based at Port Blair there has been mass coral bleaching (in 1998) around the Andaman reefs and 30-70 per cent bleaching around the Nicobar reefs. This bleaching is related to 2^0C rise in temperature from the normal temperature in the Andman Sea in 1997-1998. According to the study by National Institute of Oceanogrpahy (NIO) based in Goa coral reefs of the Kavaratti and Kadamat islands in Lakshshwadweep have suffered great damage from coral bleaching due to bacterial diseases and warmer sea temperature. The corals in the Gulf of Kutch have been bleached due to siltation.

(1) Most of the scientists have acknowledged global warming as the most significant factor of coral bleaching causing large-scale coral death. 'According to the Global Coral Reef Alliance (GCRA) every known mass bleaching occurred when temperatures were just 1^0C higher than normal during the warmest summer months' (Down to Earth, 1999).

(2) **EI Nino** phenomenon has also been related to coral bleaching. It may be mentioned that the warmest year of 1998 was also associated with the strongest EI Nino phenomenon causing further warming of the Pacific Ocean waters. It may be pointed out that EI Nino accounts for coral bleaching in certain localities only but the phenomenal increase in coral bleaching in the years 1983, 1987 and 1998 was also associated with strong EI Nino weather phenomenon.

(3) The outbreaks of coral diseases (black band disease, coral plague, aspergillosis and white band disease) cause coral death.

(4) Local factors like increase in siltation of sea waters due to mass flux of sediments and nutrients brought by thes streams from the erosion of high islands consequent upon land use changes; pollution of sea waters caused by industrial effluents, urban sewage and oil slicks; destructive fishing practices, over-fishing, clearing of marine forests around coral reefs; filling of wetlands (marine forests and wetlands trap sediments and filter pollutants and thus save corals from degradation); mining of coral rocks for building materials; collection of rare coral species etc. are also responsible for coral degradation at local and regional levels.

It may be mentioned that corals also have recovery characteristics. In the past inspite of largescale climatic change since mesozoic era (200 million years ago) like Ice Age (Pleistocene Ice Age), fluctuations in solar activities and several environmental stresses corals have managed to survive and recover. 'Reefs will not become extinct in the long term, but a single bleaching event will take reefs between 30 to 100 years to recover' (Down to Earth, August 15, 1999).

It is suggested that proper investigations and studies of coral ecosystems are necessary to understand the holistic view of association between coral ecosystems, global warming and coral bleaching so that the corals may be rejuvenated.

13.9 GREENHOUSE EFFECTS AND GLOBAL WARMING

1. Meaning of Greenhouse Effect

A greenhouse is meant for plants mainly in the cold countries where total insolation at least during winter season is not sufficient enough to support plant growth. The glasses of greenhouse are such that these allow the visible sunlight to enter but prevent the longwave intfrared rays to go out. A greenhouse also does not have any provision for artificial heating. The greenhouse effect means 'progressive warming-up of the earth's surface due to the blanketting effect of man-made carbon dioxide in the atmosphere' (Oxford Dictionary).

'In a greenhouse, visible sunlight passes through the glass and heats up the soil and warms the plants. The warm soils emit radiation in longer wavelengths particualrly in the infrared. Because the glass is opaque to these wavelengths (long wavelengths of infrared radiation waves), it absorbs and reflects the infrared (radiation waves)' (D.B.

Botkin and E.A. Keller, 1982). This mechanism keeps the greenhouse warmer than the outside environment. In nut shell it may be summerized that a greenhouse is the body which allows the shortwave incoming solar radiation to come in but does not allow the longwave outgoing terrestrial infrared radiation to escape. Carbon dioxide and water vapour act as a greenhouse in that these allow visible light of the sun to reach the surface of the earth but absorbs and reflect back the longwave outgoing terrestrial radiation mainly infrared rays back to the earth's surface and thus help in keeping the earth's surface warmer. The gases with the properties of greenhouse are called **greenhouse gases** such as carbondioxide. Halogenated gases such as chlorofluorocarbons are also greenhouse gases because these absorb longwave terrestrial radiation in the 8-13 microns band and thus help in enhancing the carbon dioxide greenhouse effect. It may be, thus, concluded that the net result of greenhouse effect of carbon dioxide, water vapour and halogenated gases, is the increase in the temperature of the earth's surface and the lower atmosphere because these gases allow solar radiation to reach the earth's surface but absorb most of the longwave terrestrial radiation and reradiate back to the earth and thus regularly warm the earth's surface and its immediate atmosphere.

2. Major Sources of Greenhouse Gases

The most significant greenhouse gas is **carbon dioxide** which is released to the atmosphere by burning of fossil fuels for different purposes in various ways as follows :

➤ Electric power stations based on fossil fuels mainly coal and mineral oil emit huge amount of carbon dioxide which reaches the atmosphere every year. These power stations are the most significant and widespread major sources of man-induced carbon dioxide.

➤ Numerous factories spread all over the world burn immense quantity of coal, mineral oil and natural gas and spew huge amount of carbon dioxide together with other undesirable gases through their chimneys into the atmosphere.

➤ The third major source is the transport sector which includes various types of vehicles run on coal and petroleum. For example, railways are large consumers of coal mainly in the developing countries, in India coal operated locomotives have been phased out and many developing countries are trying to phase out coal operated rail engines. Similarly, large fleets of automobiles (trucks, buses, cars and two wheeler-motor cycles, scooters etc.), agricultural implements like tractors, combines etc. and aircrafts all over the world burn immense quantity of diesel and petroleum each year.

➤ The fourth major source of the production of carbon dioxide is deforestation and burning of firewoods. The people are acquainted with the first three major sources of carbon dioxide as they directly spew carbon dioxide but the mechanisms of the release of carbon dioxide through deforestation are little understood by common man.

The vegetation is a very large sink of carbon dioxide because carbon dioxide is used by plants to prepare their food during the process of photosynthesis and thus huge quantity of carbon dioxide is fixed among the plants. If the forest cover is reduced through large-scale deforestation for different purposes (for increase in agricultural lands, for urban and industrial expansion, for commercial purposes etc.) the consumption of extra amount of carbon dioxide released through anthropogenic sources (e.g. human volcanoes-chimneys of factories, transport vehicles, thermal power stations etc.) to the atmosphere will be reduced and thus the concentration of carbon dioxide in the atmosphere will increase. It is believed that the deforestation has added 90 to 180 billion tonnes of carbon to the atmosphere whereas the total contribution of carbon from the burning of mineral oil and coal has been 150 to 180 billion tonnes (the base year of the beginning of the Industrial Revolution).

Minor greenhouse gases like halogenated gases (chlorofluorocarbons) and halons are released to the atmosphere during the operation and maintenance of appliances and equipments using chlorofluorocarbons as coolants and propellants (e.g. airconditioners, refrigerators, several cosmetic goods, plastic foam, fire extinguishers etc.). Besides, methane, nitrous oxides, and ozone are also green house gases.

3. Emissions of Carbon Dioxide

The climatic changes caused by global greenhouse effect due to higher concentration of carbon dioxide in the atmosphere are primarily related to the pattern of energy transfer and uses the world over. It may be pointed out that here only that part of climatic changes is being considered which is caused by greenhouse effect only.

The **IPCC Report 2007** (Intergovernmental Panel on Climate Change) revealed the following facts about global atmospheric concentration of carbon dioxide and its primary source :

- The global concentration of carbon dioxide in the atmosphere registered an increase from pre-industrial (1750 A.D.) level of 280 PPM to 379 PPM in the year 2005.
- The annual atmospheric carbon dioxide concentration growth during the period from 1960 to 2005 was 1.4 PPM per year but it registered a phenominal growth of 1.9 PPM per year during 1995-2005.
- The annual rate of increase of concentration of atmospheric CO_2 varies from year to year.
- Atmospheric concentration of CO_2 increased by only 20 PPM over 8000 years prior to the year of industrial revolution, i.e. 1750. This was because of the overdominance of natural processes of emission of CO_2 and near absence of anthropogenic source of emission of CO_2.
- Atmospheric concentration of CO_2, on the other hand, increased by 100 PPM from 1750 to 2005 due to human factors.
- The major sources of increase of atmospheric concentration of CO_2 since 1750 included the following :
  - burning of fossil fuels at alarming rate, and
  - effects of land use changes.
- As per estimate of the IPCC Report 2007 the burning of fossil fuels contributed 2/3rd of atmospheric CO_2 emissions since1750, while land use changes contributed 1/3rd CO_2 emission.
- Out of the total atmospheric concentration of CO_2 about 45 percent remained in the atmosphere, and 30 per cent was absorbed by the oceans and the remaining 25 per cent was taken by terrestrial biosphere (mainly plants).

Rapid rate of deforestion also increases the atmospheric CO_2 concentration because forests are the largest source of carbon sink as plants consume carbon dioxide to prepare their food with the help of sunlight and water through the process of photosynthesis and thus fix carbon in their biomass.

4. Emission of Methane (CH_4)

The **IPCC Report 2007** (Intergovernmental Panel on Climate Change) revealed the following trends of atmospheric concentration of methane :

- The concentration of methane in the atmosphere almost doubled from preindustrial level (1750 year) to the level of 2005 A.D. (1774 ppb, part per billion)
- The concentration of atmospheric CH_4 varied from 580 ppb to 730 ppb over the last 10,000 years but registered an increase of 1000 ppb in the last two centuries.
- The decades 1970s and 1980s registered maximum growth rate of atmospheric concentration of CH_4 but it started drastic decline since the early 1990s.
- The growth rate of atmospheric CH_4 concentration significantly declined almost to zero for 6-year period from 1999 to 2005. The

sharp decline of CH_4 denotes the fact that the annual rate of emission of CH_4 equals the rate of its removals.

- ➤ 'The slowdown in the atmospheric CH_4 growth rate since 1993 is likely due to the atmosphere approaching an equilibrium during a period of near-constant total emission.'
- ➤ The current atmospheric CH_4 levels are due to continuing anthropogenic emissions of CH_4 which are mostly biogenic and include emissions from wetlands, ruminant animals, rice agriculture and biomass (cowdung cakes) burning, with smaller contributions from industrial sources including fossil fuels-related emissions.

5. Nitrous Oxides (N_2O) Concentration

As per **IPCC Report 2007**, the following trends of atmospheric concentration of nitrous oxides (N_2O) may be underlined :

- ● The N_2O concentration in the atmosphere registered an increase of 18 percent from pre-industrial period (1750 A.D.) to 2005 A.D. (319 ppb, part per billion), due primarily to human activities, mainly agriculture and associated land use changes.
- ➤ The anthropogenic source contributes about 40 per cent of total N_2O emissions.

Table 13.6 : Emission of carbon dioxide (CO_2) in 2008

		(billion metric tonnes)	(% of global total)
	World	29.888	100
1.	China	7.031	23.30
2.	U.S.A.	5.461	18.11
3.	European Union	4.177	10.04
4.	India	1.724	5.78
5.	Russia	1.708	5.67
6.	Japan	1.208	4.01
7.	Germany	0.786	2.61
8.	Canada	0.544	1.80
9.	Australia	0.399	1.32
10.	Brazil	0.393	1.30

Table 13.7: Per capita emission of CO_2 (metric tonnes), 2008

1.	Australia	18.9	7.	U.K.	8.5
2.	U.S.A.	17.5	8.	France	6.1
3.	Russia	12.1	9.	China	5.3
4.	South Korea	10.6	10.	Brazil	1.9
5.	Germany	9.6	11.	India	1.4
6.	Japan	9.5			

Table 13.8: Gobal emission of greenhouse gases from anthropogenic sources (IPCC Report, 2007)

Green house gases	source	% of world total
1. CO_2 (carbon dioxide)	burning of fossil fuels	56.6
2. CO_2	deforestation, decay of biomass etc.	17.3
3. CH_4 (methane)	wetland, rice cultivation, cow dung etc.	14.3
4. N_2O (nitrus oxides)		7.9
5. CO_2	cement production, natural gas flaring etc.	2.8
6. F-gases		1.1

4. Greenhouse Effect and Climate change

The carbon dioxide is, in fact, a natural constituent of the earth's atmosphere. It is not necessarily a pollutant at least in the lower atmosphere but its increased concentration in the atmosphere leaves adverse effects on biological communities through changes in the thermal conditions and global radiation and heat balance. As stated in the beginning the carbon dioxide, present in gaseous form in the atmosphere, has unique properties in that it allows the solar radiation to reach the surface of the earth but tends to prevent longwave terrestrial radiation (such as infrared heat radiation from the earth) from the earth surface from escaping into outer space. This mechanism results in the increase of temperature of the surface of the earth and the lower atmosphere. It may be pointed out that about 50 per cent of the total carbon dioxide produced by anthropogenic sources (combustion of fossil fuels and burning of wood) is dissolved into the oceans and fixed by the plants in their biomass whereas the remaining 50 percent is stored in the atmospheric storage pool and thus the concentration of carbon dioxide in the atmosphere steadily increases. The trend of increasing atmospheric carbon dioxide increases the greenhouse effect which raises the temperature of the earth's surface. This mechanism may be explained in simple term as given below.

The everincreasing proportion of carbon dioxide in the atmosphere through anthropogenic sources (as discussed earlier) changes the general composition of the atmosphere and overall heat balance because carbon dioxide is more or less transparent to incoming shortwave solar radiation but it absorbs most of the outgoing longwave radiation emitted from the earth's surface. Thus the supply of additional amount of carbon dioxide to the atmosphere every year enhances the absorption of radiation of more heat emitted from the earth's surface. This mechanism (absorption of more heat emitted from the earth's surface by the atmospheric carbon dioxide) results in the warming of the lower atmosphere. This warmed lower atmosphere again reradiates heat (counter-radation) to the earth's surface which further warms the earth's surface. The net result of all these mechanism is the gradual increase of the temperature of the earth's surface and the lower atmosphere which causes changes in the climatic conditions at local through regional to global levels.

Inspite of contrasting opinions about the impact of increasing concentration of carbon dioxide in the earth's atmosphere from the burning of woods and combustion of fossil fuels on the air temperature it may be conclusively opined that there is definite positive effect of the increased concentration of the atmospheric carbon dioxide, that is there is increase in the temperature of the surface of the earth and the lower atmosphere. This increase in temperature introduces several changes in the climatic conditions at local, regional and global levels as follows:

- According to A.B. Pittock (1972) the change in the global mean temperature by a few degrees celsious caused by greenhouse effect would greatly affect the human society and agriculture.

- It is believed by some scientists that increased temperature due to increased greenhouse effect would cause **decrease in precipitation** and **soil moisture content** in the most developed agricultural regions of the world. The plants, animals and insects may be able to adjust themselves to the changed environmental conditions caused by rise in the air temperature but the whole ecosystems may be adversely damaged.
- If the concentration of carbon dioxide goes on increasing, the oceans would be required to absorb more and more carbon dioxide. More absorption and decomposition of carbon dioxide in the oceans would raise their normal level of acidity. Increased oceanic acidity would decrease biological productivity of the marine ecosystem and the decreased plant cover in the oceanic areas would change the albedo of the ocean surface.
- The increased surface temperature would cause melting of continental and mountain glaciers and polar ice caps. The resultant melt-water would raise sea-level and thus would cause flooding of coastal areas of lowland countries. According to an estimate one-metre rise in sea-level may be possible by 2050 A.D. due to warming impact of greenhouse effect. This rise in sea-level may cause flooding of 15 per cent of the agricultural lands of U.A.R. bordering the Mediterranean sea and thus about 8 million people would be displaced. Similarly, a major portion of the lower delatic region of Bangladesh would be submerged under sea-water and consequently about 8 to 10 million people would lose their agricultural lands and homes.
- It may be possible that the concentration of carbon dioxide may increase to such an extent that the total atmospheric pressure would be increased. This increase in the atmospheric pressure would broaden the absorption bands and increase the opacity of the atmosphere to the outgoing longwave terrestrial radiation which would in turn increase the surface temperature to such an extent that all the atmospheric processes which are now responsible for the existence and sustenance of all life forms in the biosphere would come to grinding halt and every thing, then, would be over. But this is an extreme situation which is unlikely to occur and this should not occur.
- The impact of greenhouse gases mainly carbon dioxide is also expected to influence rather intensify the depletion of ozone layer which would cause further rise in the temperature of the earth's surface.
- It is also argued by some scientists mainly botanists that the increased concentration of carbon dioxide in the atmosphere would increase plant production. According to an estimate an increase of carbon dioxide between 300 to 600 p.p.m. would increase vegetative productivity by about 30 per cent. It may be pointed out that this positive response of the increased carbon dioxide on the vegetative productivity is only theoretically deduced conclusion because increase in temperature is believed to have serious adverse effects on vegetation communities mainly agricultural crops.

Summary of Impact of Global Warming

- Perceptible change in the atmospheric chemistry due to increase in the concentration of atmospheric carbon dioxide since industrial revolution.
- Significant change in general composition of the atmosphere and overall heat balance.
- Gradual increase in the temperature of the earth's surface and lower atmosphere.

- Increase in the activity of hydrological cycle.
- Decrease in precipitation and soil moisture content in the most developed agricultural regions of the world.
- Whole ecosystems may be adversely affected.
- Probable increase in the acidity of the oceans and decrease in the biological productivity of the marine ecosystems and change in the albedo of the ocean surface.
- Melting of continental and mountain glaciers, Arctic and Antarctic ice sheets and Greenland ice sheets and consequent rise in sea level and flooding of coastal areas of lowland countries, and island nations.
- Total atmospheric pressure may increase.
- May increase plant production in some areas and may decrease in other areas.
- May accentuate tropical cyclones in terms of both frequency and severity. As per the report of the WMO the northern hemisphere was hottest during 2005 A.D. since the data collection in 1861. The year 2005 recorded the highest 27 numbers of tropical cyclones of which 14 storms were of the intensity of hurricanes. Hurricane Wilma, which struck Florida of the USA was termed as the strongest ever recorded hurrcane in the world. Hurricane Katrina which flattened New Orleans of the USA in August 2005 proved to be most disastrous.
- May change existing world patterns of precipitation.
- Increase in the frequency of extreme weather condition.
- biggest break up of Ward Hunt Ice Shelf of 20 km^2 off Ellesmere Island in Canadian Arctic Archipilego into 2 floating ice island as follows :
    - 4 to 5 km^2 floating island formed around July 22, 2008.
    - 14 km^2 floating ice island formed around July 23, 2008.
    - earlier break up caused floating ice island of 66 km^2 in August, 2005.
- 2 trillion tonnes of ice melted from Greenland, Antarctica and Alaska between 2003-2008 as reported by NASA.

  Greenland ice melt adds to rise in sea level by 0.5 mm per year.

Impact of Climate Change in India

India, being a party of U.N. Framework Convention on Climate Change (F.C.C.C.) published its first official document on impact of emission of green house gases on present and future climate of the country on June 1, 2004. The total annual emission of GH gases amounted to one million tonnes giving per capita emission of 1.3 tonnes/year. The over all global rise of temperature of 0.4^{0}C has caused 10-12% increase in monsoon rain in the west coast, north-west regions and north Andhra Pradesh but 6-8% decline in M.P. and adjoining areas, north-east regions and parts of Gujarat and Kerala. The temperature is likely to increase by 2-4^{0}C from 1994 level by 2040 AD. Minimum temperature will rise by 4^{0}C across the country by the year 2040. There will be decrease in rainy days by 15 days over major parts of the country. The rising temperature would dry up key river basins of India after 2040 AD (Down to Earth, July 31, 2004).

5. Remedial Measures

The first and the foremost step to arrest the problem of ever-increasing greenhouse effect and expected rise in the global mean temperature is to prevent or to reduce the release of additional carbon dioxide from the combustion of fossil fuels and through deforestation. The following measures may be suggested to decrease the increasing greenhouse effect :

(1) There should be drastic cut in the consumption of fossil fuels mainly in the developed and highly industrialized countries like the U.S.A., Russia, U.K., Germany, France, Canada, Japan etc. The Toronto

World Conference held at Toronto, Canada, in June, 1988 called for 20 per cent voluntary reduction in the emissions of carbon dioxide by the year 2005 so that the greenhouse effect may be minimized or at least may be stabilized and the possible climatic changes at regional and global levels may be prevented. The implementation of Toronto Resolutions has several practical difficulties.

(2) As per Kyoto Protocal (1997) there should be 5.2 per cent reduction in the emission of carbon dioxide below the level of 1990 emission. This agreement became effective from February 2005 when it was rectified by required number of countries though the USA and Australia have not yet signed (by 2006) the agreement.

(3) In order to solve the problem of energy crisis and energy security arising out of the implementation of the Kyoto Protocol demanding 5.2 per cent reduction in the consumption of fossil fuels from the 1990 level of emissions of CO_2 to reduce the emission of arbon dioxide the scientists must discover and develop alternative sources of energy and power and improved better technologies. For example, more serious researches are required to assess and evaluate the potentials of **methanol,** derived from methane, as the major source of fuel to be used in the transport sector. Thus methanol may be expected to be substitute for petroleum.

(4) **More advanced and efficient technologies** should be developed so that maximum energy may be derived from the use of existing fossil fuels and emission of carbon dioxide may be minimised. Virtually no attention is paid towards the restriction of the emissions of harmful carbon dioxide and other gases from the factories and vehicles in most of the developing countries. Thus the internal combustion engines should be improved and maintained properly so that maximum benefits may be derived from minimum use of petroleum and emissions of carbon dioxide, nitrous oxides etc. may be reduced to maximum degree.

(5) **Solar energy** may be developed as alternative to the conventional fossil fuel energy at least in those tropical and subtropical countries where sun light is available during most period of the year. It may be pointed out that most of the tropical and subtropical countries are either under-developed or developing nations and hence their own resources will not allow them to develop costly solar energy at the cost of primary needs of food, shelter and clothing of their people. This may be possible only when the developed countries give generous but sufficient economic aid (without interest) to the under-developed and developing countries to develop solar energy on commercial level. Will this be possible? Will the greatly developed and highly industrialized nations of the west be ready to part with the money which they have actually earned from the perennial commercial markets of the Third World Countries? **Biogas** may be considered as another alternative source of conventional energy for the domestic sector. It may be mentioned that the installation and operation of biogas plant requires sufficient quantity of cow dung which is mostly used for cooking food in many of the developing countries such as India, Pakistan, Bangladesh etc. The diversion of cow dung from the hearth to the biogas plant will not only provide fuel to the kitchens but will also provide good natural fertilizers to the agricultural crops.

(6) **Afforestation and reforestation** on a large scale will certainly reduce the greenhouse effect. It is a well known fact that the forests are big natural 'sink' of carbon dioxide. In other words, forests consume carbon dioxide to prepare food with the help of sunlight through the process of photosynthesis and thus fix carbon dioxide as carbon in their biomass. The rapid rate of forest removal at global scale has resulted in considerable decrease in the forest cover of almost all of the countries in general and subtropical and temperate countries in particular. The reduction in forest cover results in low consumption of carbon dioxide by vegetations and therefore considerable increase in the concentration of carbon dioxide in the

atmosphere. It is estimated that the forest cover of 120 million hectares can fix about 780 million tonnes of the atmospheric carbon each year. Thus if 120 million hectares of land at world level are brought under the scheme of active and effective tree plantation, 47 per cent of the total annual release of carbon dioxide from the combustion of fossil fuels and the burning of firewood may be reduced because of consumption of the gas by new cover of tree planation. According to an estimate if the forest cleared lands are reforested in Brazil, India, Columbia, Indonesia, tropical countries of Africa, Pakistan etc. about 60 percent of the total release of carbon dioxide through anthropogenic sources may be effectively reduced. It is also important to note that the rate of deforestation is increasing alarmingly particularly in the developing countries. It is very necessary to prevent deforestation if we want not to be cursed by our future generations. Greenery of the landscape is the only immediate solution of everincreasing greenhouse effect caused by everincreasing concentration of carbon dioxide in the atmosphere.

13.10 GLOBAL WARMING AND INTERNATIONAL COOPERATIONS

The international communities are well aware and are seized of the global environmental and ecological problems and various effeorts have been initiated to control global warming and halt probable climatic changes. There are several organizations, government agrencies, intergovernmental agencies, non-government organizations (NGO) which have undertaken various action plans and projects to study the relationships between man and environment, interactions between man and nature, the environmental problems resulting therefrom and remedial measures therefor. It is heartening to note that now international cooperations are forthcoming for the amelioration of the environmental and ecological problems. Efforts are being made to control ozone depletion and greenhouse effects at global level. The formulation of **Montreal Protocol** in September, 1987 under the leadership of UNO-sponsored **United Nations Environment Programme** (UNEP), the international conference on **'depletion of ozone layer'** in London, held from March 5 to 7, 1989, wherein government officials, scientists and industrialists of 180 countries participated, international conference on **ozone depletion** held in London in 1990 etc. for restricting the production and consumption of ozone depleting chlorofluorocarbons (CFCs) etc. are a few examples which reveal the seriousness of international communities for their active cooperations in tackling the global environmental problems but it is painful to pen down that still the political gimmicks, international politics, self interest and greed are the taboos of such efforts and cooperations.

Several international conferences, seminars, symposia, workshops etc. for the maintenance of environmental quality, ecological balance, ecosystem stability and biodiversity have been attended by different countries, United Nations, voluntary non-government and government organizations and several agreements and declarations have been signed. The following are the important conferences, protocols, agreements and declarations.

1. (1979) first **World Climate Summit,** 1979 in Geneva (Switzerland).
2. (1980), Conference on Industrieis and Climate, 1980, in Vienna (Austria).
3. (1985), **Vienna Convention** (Austria), 1985, for the protection and maintenance of ozone layer.
4. (1987), Agreement on **Montreal Protocol,** Montreal, Canada, 1987 (September) for reduction of the production and consumption of ozone depleting chlorofluorocarbons (CFCs) in order to check the depletion of ozone layer. The Montreal Protocol on substances that deplete the ozone signed in September, 1987 at Montreal, Canada, by 35 developed countries of the world was the first concrete step in this regard. This was initiated by United Nations

Environment Programme (UNEP). The following provisions were commonly agreed by the countries which signed the protocol.

- (i) To freeze the production of CFCs at 1986 level by 1989.
- (ii) To decrease the production of these synthetic chemical compounds by 20 per cent by the end of 1993.
- (iii) To allow further 30 per cent cut in the production of these chemicals by 1998.
- (iv) To freeze the production of halons at 1986 level starting from 1992.
- (v) Thus, the total production of ozone depleting chemicals (mainly CFCs and halons) would be reduced by 50 per cent by the beginning of 1999.

5. (1988) **Toronto Summit,** in Toronto city of Canada, for the reduction in the emission of carbon dioxide. The summit aimed at 20 per cent cut in the emission of carbon dioxide by 2005 AD but the developped countries backed out from the agreement on the pertext of non-availability of reliable data of emission of green house gases.
6. (1988), Constitution of **Intergovernmental Panel on Climate Change** (IPCC) for the study of climatic changes by United Nations Environment Programme (UNEP) and World Meteorological Organization (WMO) in 1988. This panel was assigned the main task of presenting report on effects of greenhouse gases on the earth from time to time.
7. (1990), **Second World Climate Summit** was held in 1990 to search effective measures to check the emission of greenhouse gases and Intergovernmental Agreement Commitee was constituted.
8. (1992). The United Nations Conference on Environment and Development—UNCED, better known as **First Earth Summit** or **Rio Summit,** was organized in June, 1992 in Rio De Janeiro city of Brazil which was attended by 178 countries which signed the **Climate Change Convention.**
9. (1994). The signed climate change convention during 'first earth summit' was given practical shape which aimed at reduction in carbon emission and to stabilize the emission at 1990 level by 2000 AD but it could not be implemented in letter and spirit by the allotted time frame.
10. (1995), The first summit of the advocates of Climate Change Convention, better known as **Berlin Summit,** was held in June 1995 in Berlin city of Germany but no agreement could be arrived at for the fixing of amount of emission of carbon dioxide by different countries.
11. (1996), The second summit of the advocates of the Climate Change Convention was held in Vienna city of Austria in July 1996 but this summit also proved unsuccessful as no agreement on the amount of emission of carbon dioxide could be struck.
12. (1997), United Nations **Second Earth Summit,** was organized in New York city of the U.S.A. from June 23 to 27, 1997 and was represented by the representatives of 170 countries and 70 heads of the government. This summit aimed at the evaluation of the implementation of **Agenda 21** of the first earth summit organized in Rio De Janeiro in 1992.
13. (1997). The third summit of the advocates of the climate change was held from December 1 to 10, 1998, in the Kyoto city of Japan. After prolonged discussion an agreement, known as **Kyoto Agreement,** to 5.2 per cent cut in the emission of carbon dioxide by the developed countries, was signed.
14. The 10th climate change meet known as Tenth Conference of Parties (CoP-10) of the United Nations Framework Convention on Climate Change (UNFCCC) was held from Dec. 6 to 17, 2004 in Buenos Aires (Argentina) to

combat global warming and implement Kyoto Protocol but nothing substantial could be achieved as 'political will for concerted global solutions (of global warming and climate change) has seriously waned' (Down to Earth, Jan 15, 2005, p. 22).

Besides, the **Stockholm Conference** in 1972 (Sweden), **Desertification Conference** in 1972 in Nairobi (Kenya), **Hague Declaration** of March, 1989, **Helsinki Declaration** of May, 2, 1989 etc. are positive steps towards the maintenance of environmental quality. It may be mentioned that about 158 agreements, delcarations, protocols etc. have been signed upto 1997.

First Earth Summit

(Rio Summit)

United Nations Conference on Environment and Development (UNCED), better known as **Earth Summit** or Simply **Rio Summit** was organized from June 3 to 14, 1992, in Rio De Janeiro city of Brazil under the aegis of United Nations for the protection of the earth and its environment, maintenance of ecological balance and to enrich bodiversity. The conference was attended by the representatives of 178 developed and developing countries. The primary objectives of the conference were to arrive at commonly acceptable agreements and their implementation to tackle the problems of global warming, depletion of ozone layer and ozone hole, deforestation, biodiversity, weather and climate change, acid rain, sustainable development etc. The following were five important agenda of the conference : (i) rise in global temperature (global warming), (2) forest protection, (3) biodiversity, (4) agenda 21, and (5) Rio declaration. Only two aspects of global warming and forest conservation of Rio Summit are being discussed here as only these two are directly concerned with global warming and climate change.

1. **Global Warming :** A rise of 1.5⁰C in the atmospheric temperature has been reported for the last 75 years (upto 1995). Some sources put this rise from 0.3⁰C to 0.6⁰C. Greenhouse gases (carbon dioxide, methane, chlorofluorocarbon, nitrous oxide etc.) have been identified as major factors of global warming. It is, thus, apparent that the global warming is due to anthropogenic economic activities. Greenhouse gases are emitted from industrial establishments, automobiles, domestic appliances etc, and these gases are concentrated in the lower atmosphere, thereafter they increase air temperature. The relative shares of carbon dioxide, chloroflurocarbon, methane and nitrous oxides were 51%, 20%, 16% and 16% respectively upto 1990. The detailed information of emission of greenhouse gases and global warming have already been presented in the preceding section 13.9 and the causes, mechanism and adverse effects of greenhouse gases and ozone depletion have been discussed earlier in this chapter. It may be pointed out that developed countries are themselves responsible for ozone depletion and creation of ozone hole.

An attempt was made at the time of **earth summit** for an agreement to reduce the emission of greenhouse gases at 1990 level by 2000 AD by the developed countries to tackle the problem of global rise in temperature and its consequential adverse effects in future but no concrete agreement could be arrived at. It was commonly agreed upon to cut the emission of greenhouse gases but neither any concrete fromula nor any time limit could be decided for this purpose.

2. **Forest Conservation :** At the time of earth summit all the participants expressed deep concern and anger at the rapacious and reckless cutting of forests. It may be pointed out that according to an estimate about 8,000 years ago 8,000 million hectares of land were covered with forests which decreased to 3,000 million hectares by 1998. Thus, the modern society has already consumed two third of world forest cover. It may be remembered that one third tropical rainforests were cleared by 1972 and the loss of remaining rainforests began at the annual rate of 0.5 per cent (i.e. 100,000 km² forest area per year). The annual rate of loss of rainforest reached the figure of 170,000 km² by the year 1992.

According to United Nations data (1980) forest area is being lost at the annual rate of 2,000,000 hectares in Asia and Pacific region. Even in Brazil 620,000 km^2 of forest area was cleared in the decade 1980-90. India is losing its forest cover at the rate of 2.8 per cent per year. It may be pointed out that the developed countries have already consumed major portions of their forest covers. It may be underlined that the tropical rainforests are richest in biodiversity and have medicinal importance.

Developed countries plead for imposing restrictions on cutting of tropical rainforests in order to use them for medicinal purposes and as natural carbon sinks for the absorption of emitted carbon dioxide from their industrial establishments and thermal power plants. Keeping this fact in mind the United States presented a proposal of forest conservation which was strongly supported by the countries of European Communities at the time of first earth summit. The American proposal was based on the logic that forest wealth is the commonly shared property of the world community and hence an international law should be enacted for its conservation and maintenance. It may be mentioned that the United States clevery excluded private forests from the purview of the proposed forest conservation law because most of forests in the U.S.A. come under private ownership. Thus, the U.S.A. on one hand tried to delink its forest resources from the proposed international law and on the other hand, attempted to claim right on the forest resources of the developing countries. The developing countries smelt the trick of the U.S.A. and under the leadership of India and Malasia rejected the U.S. proposal outrightly on the ground that forests are their national property and hence they cannot be brought under any international law. Developing countries strongly pleaded that the developed countries should control the emission of carbon dioxide in their own regions. Thus, the proposal of forest conservation was finally rejected.

Second Earth Summit

The second earth summit was held from June 23 to 27, 1997 in New York city of the U.S.A. in order to evaluate the progress and implementation of proposals and Agenda 21 which were agreed during the **First Earth Sumit** organized in 1992 in Rio De Janerio city of Brazil. The second earth summit was attended by the representatives of 170 countries with 70 heads of government. This summit is also known as **Plus-5 Summit** because this summit was organized after 5 years from the first earth summit (Rio Summit) and the programmes and action plans (accepted during Rio Summit) were discussed and reviewed but ultimately no concrete and fruitful results could be achieved because no agreement could be made on any agenda. Various agenda which were endorsed during Rio Summit e.g. financial help for check on global rise in temperature, effective cut in the emission of greenhouse gases, law of forest conservation, sustainable agricultural development, conservation of biodiversity, eradication of poverty etc. could not be sincerely implemented. It may be pointed out that the aforesaid problems could not be attendd sincerely and hence could not be solved rather they were further aggravated during 5-year period (1992-97) because (a) the emission of carbon dioxide further increased from 1992 to 1997 (but slightly decreased in 1998), (b) the pace of deforestation got accelerated, (c) global warming could not be controlled, (d) poverty and population growth have increased etc. The U.S.A. became an effective barrier in endorsing the proposal for curtailing the emission of carbon dioxide and the agenda was postponed to be considered at **Kyoto Summit** to be held in December, 1997 in Japan. At the end of the summit a declaration of voluntary contribution of 0.7 percent of national product by the developed countries to developing countries was signed but the developed countries did not implement this declartion sincerely as they contributed only 0.27 per cent of their national product to aid fund. World Wild Fund (WWF) and World Bank assured to take the responsibility of forest conservation.

Kyoto Protocol

A summit to reduce global warming was held from December 1 to 10, 1997 in Kyoto city of Japan and an agreement to this effect was also signed. This summit was attended by the representatives of 149 countries. This agreement is popularly known as **Kyoto Protocol** or **Kyoto Thermal Treaty.** The following are the main items of this historic agreement.

(i) A proposal of 30 per cent cut in the emission of carbon dioxide by 2008-12 A.D. was presented by the island nations on the fear that the temperature is estimated to rise 2^0C to 3.5^0C at the present rate (1997 level) of global warming but the proposal was strongly opposed by the developed and industrialized countries. Ultimately an agreement on 5.2 per cent cut from 1990 level of carbon emission could be signed. This cut in carbon emission would be implemented by 11 industrialized countries. It may be pointed out that the U.S.A., European community and Japan agreed to curtial 7 per cent, 8 per cent and 6 per cent emission of carbon dioxide respectively but the developing countries did not agree for any cut in carbon emissioin.

(2) According to this agreement industrial countries can have mutual transfer of fixed quota of cut in the emission of greenhouse gases. For example, if two countries have been allotted the quota of 6 per cent cut each in carbon emission, after mutual understanding one country may curtail only 4 per cent carbon emission while the second country wil have to cut 8 per cent carbon emission and can claim royalty for additional 2 per cent cut from the first country. This is termed as **carbon trading** or **hot air trading.** As a consequence of Kyoto Protocol Russia and Japan have struck such deal between them. Japan found it difficult to implement the quota of 6 per cent cut in carbon emission from 1990 level. On the other hand, Russia can meet its target of zero per cent rise in carbon dioxide because of its economic recession. 'Under the agreement Japanese companies would invest in 20 Russian power plants and industries to cut greenhouse emission. These reductions of Russian emissions would be added to Japanese carbon dioxide balance sheet' (Down to Earth, July 31, 1998).

(3) The Kyoto Protocol and Agreement would automatically be invalidated if at least 60 countries of Conference of Parties (CoP) do not endorse and implement its provisions and resolutions. The protocol was to be effective from June, 1999. A fine would be imposed on those countries which do not adopt the protocol.

(4) **A Clean Development Fund** (CDP) would be established which would be funded by the fines realized from the countries which flout the protocol.

Review of Kyoto Protocol : One positive outcome of the Kyoto Conference on Climate Change and Kyoto Protocol is that the developed and developing countries accepted at least in principle that some concrete steps should be initiated to check climatic change due to rise in global temperature. The developing and poor countries succeeded in managing unanimity on the point that reduction in the emission of greenhouse gases would not be binding on them. It may be pointed out that the emission of greenhouse gases from a few big developing countries like China, India, Brazil etc. would also increase substantially in near future. It is to be remembered that at the time of Kyoto Protocol (1997) the per capita emission of greenhouse gases from the developing countries was 2.4 tonnes per annum against annual per capita emission of 11.9 tonnes from developed countries, thus, the developing countries should also be prepared for future cut in the emission of greenhouse gases. In fact, Kyoto conference could not be as much effective as expected because of rigid attitude of developed countries and futile efforts to blame each other for global warming. It may be pointed out that in order to transfer **environment friendly technologies** from developed countries to developing countries to check the emission of greenhouse gases **Global Environment Facility (GEF)** has been established with the help of World Bank, United Nations Development Programme **(UNDP)** and United Nations Environment Programme **(UNEP)** but no concrete steps could be initiated by 1998.

It may be concluded that 'the Kyoto protocol, agreed in December 1997, was the first step to curtail emissions of the industrialized world. It is now being used to set up a trading system to buy and sell carbon emission. The Kyoto protocol is increasingly being understood not as an **environmental agreement** but a **trading agreement'** (Down to Earth, July 31, 1998).

The Kyoto Protocol, envisaging 5.2 per cent reduction in CO_2 emission from the 1990 level emission was rectified on Feb. 17, 2005 and would be effective upto 2012 A.D. but the USA and Australia did not sign the agreement.

Carbon Trading

As per Kyoto Protocol carbon trading simply means that in order to implement the mandatory cut in the overall carbon emission by at least 5.2 per cent below 1990 level between 2008-2012 A.D., the industrialized developed 'countries and their private corporations could invest in projects in developing countries which are carbon efficient. The net benefits of carbon reduction would accrue to the industrialized country or private corporation in its balance sheet of carbon accounting. Developing countries would be selling **'certified emission reduction'** units' (Down to Earth, July 31, 1998). It is proposed to set up a global Executive Board (EB) to superwise carbon trading and numerous certification agencies will be authorized by the Executive Board. Several organizations and establishments have floated various brokers for managing carbon trading. For example, Carbon Investment Fund by the World Bank, Portfolio of Projects of Interest by the Asian Development Bank, Emission Trading Corporation by the United Nations Conference on Trade and Development (UNCTAD), Intergovernmental Panel on Emission Trading by the United Nations Environment Programme (UNEP), Clean Development Mechanism (CDM) by the United Nations Development Programme (UNDP) etc. are a few efforts to manage carbon trading.

It may be remarked that 'after the Kyoto meet, one thing is clear, climate change has been taken out of the world of the environment lobby to the big bad world of money. The key issue—between the buyers and sellers of this commodity (carbon emission) which has no clearly defined borders—is to trade without limits and without the interference of prickly issues of the property rights of the poor……Rich nations want to reduce their emissions on the cheep……Politics is now driving science. The threat posed by global warming has been forgotten' (Down to Earth, July 31 1998).

A conference known as **Bonn Convention** to deliberate climate change affair was held in Bonn city of Germany in June, 1998 in order to make carbon trading effective. It may be mentioned that the industrialized countries in general and the U.S.A. in particular became frenzy about their greed to start carbon trading, say **trading in the atmosphere,** without further delay. The countries involved in negotiating carbon trading and rules for it has been identified to fall in three blocks viz. (1) **The JUSSCANNA Block,** comprising U.S.A., Australia, Canada, Switzerland, Japan, New Zealand and Norway, is led by the US. This block has now been joined by the Russian Federation and Iceland also. This block better known as the **Free Raïders Group,** is over enthusiastic in the implementation of carbon trading and is demanding **meaningful participation** of developing countries in the programme to curtail carbon emission. (2) The **EU Block,** better known as **the Free Bubblers Group,** comprising the countries of European Union, desires to "bubble together" i.e. all the countries of EU can meet their target of cut in the emission of greenhouse gases together (in aggregate). (3) **The G-77 and China,** known as The **(Not) for Sale Group.** "These countries do not have commitments to curtail their emissions but they are required to "assist" the industrialized nations meet their targets by selling carbon units' (Down to Earth, July 31, 1998).

These three blocks sharply differed on two basic issues of carbon trading viz. (i) approach towards carbon trading, and (ii) approach towards three mechanisms of carbon trading as laid out in

Kyoto Protocol (December 1997), e.g. (a) **Joint Implementation** (Article 6), (b) **Clean Development Mechanism—CDM** (Article 12), and (c) **Emissions Trading** (Article 17). There was a lot of discussion between trading and non-trading blocks but 'it would be right in a way to say that the meeting of Bonn did flag important issues and provided countries with an opportunity to size up the situation before they come to the negotiations in Buneous Aires city of Argentina at the Conferences of Parties (CoP-4) to be held in November 1998' (Down to Earth, July 31, 1998).

The convention of Conference of Parties-4 (CoP-4) held from November 2 to 12, 1998 in Buenos Aires (Argentina) fixed 2000 A.D. as the deadline for the implementation of Kyoto Protocol which envisaged reduction in the emission of greenhouse gases by 5.2 per cent below the level of 1990 emission by 2008-2012 A.D. It may be concluded that efforts are being made through periodic meetings of the UN Framework Convention on Climate Change (FCCC), Conference of Parties (CoP) and many other conventions and conferences to tackle the problems of global warming and related environmental problems and climate change.

Tenth CoP Meet (2004)

The Tenth Conference of Parties (CoP-10) of the United Nations Framework Convention on Climate Change (UNFCCC) was held from Dec. 6 to 17, 2004 in Buenos Aires (Argentina) 'to discuss the development, deployment and diffusion of technologies to mitigate climate change. What they agreed was merely to continue focussing its work on exchanging information and sharing experiences and views, among members, on practical opportunities and solutions to mitigate climate change' (Down to Earth, Jan. 15, 2005).

13.11 URBANIZATION AND CLIMATE

The process of urbanization, a man-induced phenomenon, results in the transformation of mostly natural landscape of a richly vegetated countryside into the development of cities and towns characterized by concretionary structures which greatly modify the pre-existing climatic conditions of the countryside of the pre-urbanized stage. Thus 'a city generates its own distinctive climate' (W.R. Rouse, in K.J. Gregory and D.E. Walling, 1981) which is an example of 'man-modified or maninduced climate'. The various factors of well developed city of fairly a large size viz. density of buildings, height of buildings, size of city, size of human population, breadth of roads and streets, nature of storm drains, open unbuilt spaces, nature of urban vegetation, topography and other environmental conditons of the surrounding countryside or rural areas, level of industrial development of the concerned city, nature and amount of pollutants in the city atmosphere etc. modify the climatic conditon of a city and thus generate a typical **'urban climate'**. The urbanization affects the local climate through the formation of heat island, changes in the patterns of air flow both horizontal and vertical, creation of pollution dome above the city, alteration of urban hydrological regime etc.

1. Urbanization and Heat Island

The process of urbanization changes the radiaton and heat balance at local level which becomes regional in character when the effects are extended to larger areas mainly in big industrial belts. The higher temperature in the CBD (Central Business District) or the City Centre (known as **'chowk'** in Indian cities) is very often called as **urban heat island** or simply, a **heat island**. If we have a 'thermal cross section' of a city it appears that temperature decreases outward from the city centre.

It may be pointed out that the temperature decreases slowly from the city centre towards the outer parts of the city but at the boundary of the city and the countryside there is sudden drop in the air temperature. The heat island becomes most pronounced at night because the temperature difference between the city centre and the rural surroundings or countryside is normally 6^{0}C in most of the large cities but some times the difference of temperature becomes 12^{0}C or even more. 'The magnitude of the urban heat island shows a clear relationship to city size and to wind speed. The larger the city the stronger the winds which are necessary to dissipate the heat island effect' (T.R. Oake and F.G. Hannell, 1970; quoted by W.R. Rouse, 1981). It is significant to note that the thermal effect of urban heat island is confined to about 300 m above the city centre and beyond this height temperature countinues to decrease upward following the general rule of normal lapse rate.

The radiation and heat balance of an urban centre is modified because of more absorption of incoming shortwave solar radiation which causes higher temperature of the masonary ground surface because of two factors viz. (i) The transformation of natural landscape into urban centre results in the absence of plant cover except a few planted trees, bushes, hedges, grassy lawns and gardens scattered in the different parts of the city. Thus the solar radiation in the absence of vegetation reaches the ground surface with almost full intensity. (ii) The masonry structures of the roofs of the buildings, pavements and roads and streets largely absorb the incoming solar radiation. Further more, the total lack of moisture does not facilitate evaporation and thus in the absence of evaporative cooling (evaporation involves use of heat to convert water into gaseous form and causes lowering of air temperature. This process is called evaporative cooling of the air) the temperature of the urban centres increases.

The following factors and mechanisms may be held responsible for the creation of an urban heat island :

- ➤ As referred to above the masonry structures of the urban centres absorb solar radiation more efficiently than vegetated covers. More over, the incoming solar radiation reaches the city surface with full intensity.
- ➤ Man-induced heat mainly in the larger industrial cities and even in other metropolitan cities emitted from industrial processes, space heating and cooling, power stations etc. supplement the heat received through solar radiation. According to the study conducted by J.D. Kalma (1974) about the assessment of man-induced heat in the city centre of Sydney (Australia), man-made heating can exceed 25 watts per square metre which is equivalent to almost 50 per cent of incoming solar radiation during winter season. The contribution of man-induced heat to that of the solar radiation drops to 25 per cent during summer season because of increase in incoming solar radiation and decrease in space heating due to rise in air temperature.
- ➤ The construction materials used in modern cities and the walls and the pavements also positively contribute to the heat budget of the urban islands. The building construction materials such as bricks, concretes, sands and cements, pebbles, rocks and rock pieces, bitumen etc. absorb more solar radiation more efficiently. Similarly, the masonry surfaces of the vertical walls absorb solar radiation and reflect it to the ground pavement surfces and to other vertical structures during daytime where the solar energy is properly stored. It may be pointed out that normally one expects lower temperature in the city area than the surrounding countrysides because of expected rapid loss of heat through longwave radiation from the bare and dry surfaces of the city but the heat island is maintained even during night because of the fact that the heat stored in the pavements, walls and ground surfaces during daytime is released during night and hence relatively higher temperature of the urban centre is maintained. So the urban heat island is all-season phenomenon.
- ➤ Urban areas are provided with masonry storm drains which are constructed in accordance with the slope gradient of the city area. Consequently, the rainwater and domestic waste water are not allowed to collect rather

these are quickly disposed off through efficient and rapid drainage system. Thus the evaporative cooling effects of such waters are reduced. This mechanism ultimately does not help in lowering the temperature.

- There is positive relationship between the intensity of urban heat island and the size of human population and density of buildings. Very closely spaced buildings (high density of buildings) and narrow roads and streets tend to increase temperature of the urban centre more than the widely spaced buildings (low density of buildings) and relatively wider roads and streets. 'Measurements in the USA suggest that a ten-fold increase of city population has an average warming effect on the centre of 1^{0}C. It is also found that the urban heating effect is removed by winds of sufficient strength ranging from 4.1 m.s^{-1} for a city of 33,000 population to 11.8 m.s^{-1} for a metropolis of 8 million' (T.R. Oake, 1973 1976, quoted by J.E. Hobbs, 1980).

2. Heat Island and Weather Phenomena

Though the presence of urban heat island is all-season and daily phenomenon but its effects are more prominent at night. Urban heat island generates thermal anomaly in the **rurban** environments i.e. between urban area and its surrounding rural countryside area wherein the difference of temperature between these two areas and their corresponding environments (that is urban-rural temperature difference) becomes 5^0 to 6^{0}C during daytime and rises to 12^{0}C or even more at nights. This diurnal range of temperature between the urban-rural environments generates convectional air circulation during night because of the formation of low pressure cell in the heat island of the city centre because of high temperature in comparison to the temperature of the surrounding areas.

The air of the heat island is warmed up and thus rises upward to the limit of **pollution dome** (formation of thick cover of polluted air atop of urban centres from where the ascending warm and light air spreads laterally outward in all directions from the city centre-heat island). On the other hand relatively cooler air of the surrounding rural areas flows inward to converge at the city centre from where it is again warmed up and rises upward. The spreading warm air over the city area is cooled and thus descends in the surrounding rural areas. Thus the mechanism of warm air moving up from the city centre (heat island) and relatively cooler air moving in form the surrounding rural areas towards city centre completes a cycle which is commonly known as **urban wind cell** and the air circulation cuased therefrom is called as weak **counter breeze** or **countryside breeze.**

The convectional system of air circulation consequent upon the formation of urban heat island as discussed above results in more cloudiness over urban areas and consequently more precipitation. In fact, the effects of urban agglomerations have been positiviely correlated with precipitation amount though in spasmodic manner. The climatological studies conducted in the urban areas of central Europe have revealed an increase of annual amount of precipitation by about 10 per cent. The urban environment together with the heat island induces precipitation through (i) increased water vapour input provided from the cumbustion of hydrocarbon fuels in the power houses and transport vehicles, and thus increase in absolute humidity, (ii) increased number of hygroscopic nuclei due to emission of particulates from factories and combustion engines, (iii) mechanical turbulence caused by the roughness factor of city surface, (iv) increased thermal turbulence and convection caused by higher temperature of the heat island (city centre) etc.

Thermal convection caused by heating of air and consequent uplift due to relatively higher temperature of the city centre intensifies any rainstorm or thunderstorm or cyclone passing through the concerned city and thus causes more precipitation than the normal value. 'For example, it has been found that thunderstorms over the city of

London produce 30 per cent more rainfall than thunderstorms over the surrounding country. Increased precipitation over an urban area is estimated to range from 5 to10 per cent over the normal for the region in which it lies' (A.N. Strahler and A.H. Strahler, 1976). Cloudiness is also reported to increase by 5 to 10 per cent over a city. S.A. Changnon (1969) has also reported based on his 'Recent studies of urban effects on precipitation in the United States of America', that the average annual precipitation over urban centres is usually 7 per cent greater than the surrounding rural areas.

It may be pointed out that a few studies have contradicted the concept of increased precipitation over urban centres because of thermal convection caused by urban heat islands. 'A study in the New York metropolitan area, for example, indicated no effect on daily precipitation patterns. Nevertheless, it does seem likely that convection related to an urban heat island can produce a significant effect on precipitation in some cities such as Washington D.C. where a study by Harmack and Landsberg (1975) showed that the extra increment of heating supplied to a convective cloud by the urban fabrics is often the trigger for the occurrence of convective precipitation (H.E. Hobbs, 1980).

3. Urbanization and Other Weather Phenomena

Urban centres affect rather modify patterns of air circulation in and above the cities and their immediate surroundings and the modified air circulation in turn affects temperature, humidity, pressure and precipitation patterns. Tall buildings in the cities obstruct free flow of air and thus retards wind speed. According to the findings of H.E. Landsberg (1970) annual mean wind speed is usually 20 to 30 per cent less over the cities than the surrounding countryside and the speed of extreme gusts (a sudden violent burst of wind) is 10 to 20 per cent lower while the calms (cool gentle wind with very low speed) are 5 to 20 per cent more frequent in the cities than their immediate surrounding countrysides. According to the findings of T.J. Chandeller (1976) based on the measurement of wind speed during different seasons of a year (December-January, March-May, June-August and September-November) at 0100 GMT (Greenwich Mean Time) and 1300 GMT at London Airport (Heathrow) and Central London city, urban wind speeds are greater than those in the surrounding rural areas during night (at 0100 GMT) wherein average annual wind speed is about 2.5 metres per second over the central London whereas it is only 2.2 metres per second over London Airport but daytime wind speed is higher over London Airport (2.9 meters per second) than that over central London (2.2 meters per second). The pattern of airflow in the cities located in the coastal areas is complicated by sea breezes (from the sea towards the coastal land, during daytime) and land breezes (from the coastal land towards the sea) during night. This mechanism of land and sea breezes is responsible for the circulation and recirculation of atmospheric pollutants over the cities.

Urban air pollution largely modifies the climatic conditons of large urban centres in a veriety of ways. Most of the urban pollutants are released to the atmosphere as waste products from different combustion processes mainly through human volcanoes (chimneys of factories) and automobiles. The main pollutants emitted through the chimneys of factories include unoxidised nitrogen, carbon dioxide, coarse ash, fine smoke, sulphur dioxide etc. whereas the pollutants emitted from automobile exhausts include lead, unburnt hydrocarbons, carbon monoxide, nitrogen monoxide, water vapour, carbon dioxide and unoxidised nitrogen. These pollutants form a thick layer over the cities generally at the height of 1000 m. Such thick layer of the concentrated pollutants over a city is calleld as **'climatological dome'** or **'pollution dome'**. 'This urban particulate concentration is responsibile for absorbing or reflecting up to 20 per cent of the solar radiation which arrives above the pollution dome and can also reduce soalr radiation over the downward countryside' (W.R. Rouse, 1981). The urban pollutants introduce several modifications in the urban climate. The concentration of pollutants depends on several factors viz. amount of pollutants emitted into the atmosphere, air circulation which controls the movement and mixing of pollutants, the depth of mixing layer which itself depends on the height and thickness of inversion layer etc.

Higher concentrations of particulate pollutants decrease visibility in the city and form dense fog when there is abundant moisture in the urban air. In fact, particulate pollutants provide numerous hygroscopic nuclei which in the presence of sufficient available moisture increase the incidence of fog by100 per cent and water vapour readily condenses around numerous hygroscopic nuclei and thus forms innumerable tiny water droplets which form fogs. When fogs are formed due to the combinations of smoke, dust, aerosols, water droplets and nitrogen dioxide, these are called smogs or **urban smogs.** These smogs when associated with sulphur dioxide become poisonous because the resultant form of sulphuric acid becomes very much injurous to organisms in general and human beings in particular.

Photochemical smogs caused due to the reactions of nitrogen dioxide, hydrocarbons and sunlight become very dangerous when they mix up with ozone. The nitrogen dioxide emitted from anthropogenic sources after absorbing ultraviolet rays of solar radiation is decomposed into nitric oxide and atomic oxygen which combines with molecular oxygen and forms ozone. This process is called photochemical process. The photochemically produced urban smogs reduce atmospheric visibility, reduce solar radiation and influence precipitation. The cities located in the valleys are very often affected by persistent inversion of temperature. This inversion of temperature intensifies fog and smogs and enhances their duration. Thus persistent smogs in the cities cause irreparable loss to human health and biological communities. The poisonous smogs of Donora town located in Pennsylvania (U.S.A., October 26, 1948), of Meuse Valley of Belgium (December, 1930) and of London (1952) are a few examples of deadly after-effects of urbanization.

14

CLIMATE CHANGE

14.1 MEANING AND CONCEPT

Variability, in both time and space, is an inherent feature of climate, as the atmosphere is always in the state of turmoil and instability leading to variations in weather and climatic conditions. The climatic change, thus, is defined as variations and shifts in weather conditions over space and time of different scales and magnitude resulting into change of climatic type for example, from warm and moist climate to warm and dry climate, from warm and moist climate to cool and moist climate (as happened during Carboniferous period in India) etc. In fact, climatic change refers to drastic or secular changes in heat balance of the earth-atmosphere system, moisture, cloudiness and precipitation caused by either external factors such as variations in orbital characteristics of the earth, solar variability (fluctuations in radiation from the photosphere of the sun), tectonic processes (mainly plate tectonics and displacement of continents and ocean basins), vulcanicity, changes in atmospheric composition in terms of concentration of atmospheric aerosols and carbon dioxide contents etc. or by internal factors such as exchanges of energy between the atmosphere, hydrosphere, lithosphere and cryosphere (ice covered surfaces of both lithosphere and hydrosphere) or by both, at local, regional and global levels. The **climochronology** (history of palaeoclimates) reveals the fact that climates have changed in the geological past and hence it is opined that 'the world's climates have changed in the past, are changing now, and there is every reason to expect that they will change in future' (*J.E. Hobbs*, 1980). If the change is law of nature, the change in climates is a reality because the climate of a region is not fixed and static rather it goes on changing. Some times, the changes are cyclic and rhythmic, such change is called **climatic cycle**. It may be mentioned that James Hutton (a Scottish geologist) while propounding the **concept of uniformitarianism**, postulated the concept of **cyclic nature of earth's history**. The example of occurrences of ice ages during (1) pre-Cambrian period (850-600 million years before present, mbp = million years before present), (2) Ordovician period (450-430 mbp), (3) Carboniferous-Permian periods (300 mbp), and (4) Pleistocene period (2-3 mbp) validates the concept of **cyclic nature of climatic changes.**

The climatic changes are supposed to be quick and rapid rather than slow and gradual but this may not be always true as climate changes both gradually and rapidly, partly and drastically. For example, the climatic change, which occurred during Jurassic period leading to mass extinction of dinasaurs due to sudden onset of cold climate, was rapid and instantaneous. In fact, the rate of climatic changes depends on the nature of causal factors. The rapid Jurassic climatic change is related to sudden collision of the earth and a giant meteor and consequent release of enormous amount of dusts in the atmosphere. One cannot infer the nature of long-period climate on the basis of present-day climatic conditions. It is also an observed fact that the 'cool periods of earth history are periods of greater than normal climatic instability' (*J. E. Hobbs*, 1980).

The human society with present-day weather conditions is seized with the problems of possible climatic changes in near future. The most significant global environmental problem faced by the world community is **global environmental changes** (GEC) leading to probable climatic changes consequent upon global warming resulting from a host of causal factors, namely ozone depletion, increase in the emission of green house gases at alarming rate, deforestation etc. The probable net result of global warming would be climatic changes at local, regional, and global levels. The international communities are scared of catastrophic adverse effects of future climatic changes on different spheres of man and nature, e.g. deglaciation and sea level changes, submergence of island nations and major coastal lowlands, atmospheric dynamics including evaporation and precipitation, global radiation balance, photosynthesis and ecological productivity, plant and animal communities, human health and many more. It may be summarized that climatic change is a reality, it has changed in the past, it is changing at the present, and it will change in future. The change of climate may be slow and gradual, rapid and catastrophic, periodic, semi-periodic or non-periodic, short-term or long-term, may be at local, regional and global scales, it may be due to natural factors or anthropogenic factors. It is, thus, necessary to discuss various aspects of climatic changes, namely scales of climatic changes (both spatial and temporal scales), indicators of climatic changes (i.e. evidences of climatic changes), reconstruction of palaecolimates (climochronology), causes of climatic changes, theories of climatic changes, and effects of climatic changes on both nature and biological communities including human beings.

14.2 SCALE DIMENSION

The climatic variations and changes are viewed in terms of temporal and spatial scales depending on the purpose of studies. The temporal scales of climatic changes range from a very micro-scale involving 10-day period to macro-temporal scale involving thousands to millions of years. 'The variability may be periodic (A), quasi-periodic (B), or non-periodic (C), or alternatively it may show a progressive trend' (*Barry* and *Chorley*, 2002). It may be mentioned that spatial and temporal scales of climatic changes are correlated e.g. as the temporal scale of change becomes shorter, the area also becomes smaller. In other words, the changes may be more perceptible and pronounced in localized area during short period of recorded climatic data, but if we consider climatic data at regional level involving large countries or continents, and at global level, the local level changes are overshadowed. Thus, the climatic changes may be viewed in terms of three temporal scales, namely (i) macro-temporal scale (millions of years), (ii) meso-temporal scale (thousands of years), and (iii) micro-temporal scale (hundreds of years). These three temporal scales correspond to global, regional, and local spatial scales. At regional and local spatial scales the climatic variability can be looked upon at even shorter temporal scales which may range from very micro-temporal scale to increasing time span e.g. (1) 10 days time scale, (e) 10-100 days time scale, (3) 100-1000 days time scale, (4) 1000-10000 days time scale etc. It may be remembered that such changes may be detected only if the instrumented data are very accurate and regular. The climate changes which occurred in the past, say before the industrial revolution, cannot be viewed in such a micro-temporal scales.

Generally, climatic changes are considered at two levels e.g. (1) **short-term changes,** and (2) **long-term changes.** Short-term climatic changes involve the consideration of changes in the energy balance of the earth-atmosphere system leading to periodic changes in weather and climate. This temporal scale involves time span ranging from few years to thousands of years. Short-term climatic changes are either inter-annual or they may persist for many years and are generally caused by anthropogenic factors. On the other hand, long-term climatic changes persist for thousands to millions of years and are exceedingly slow. These are always caused by natural factors.

14.3 INDICATORS OF CLIMATIC CHANGES

The evidences of climatic changes in the past, which are utilized in the reconstruction of **climochronology** (history of palaeoclimates) are called indicators of past climatic changes. The riddle of reconstruction of palaeoclimates is a fascinating puzzle, the solution of which basically depends on **proxy data** (which include alternative sources of data as substitutes for real data) and logical deductions by the investigators. It may be mentioned that recorded data of weather and climate are available only since industrial revolution, more precisely for the last 100 years or so, and hence proxy data for recorded data are the only indicators to decipher the pages of past climatic history and changes on the basis of Huttonian theory of **uniformitiarianism** (postulated by Scottish geologist, James Hutton in the year 1785). This theory was based on two concepts of Hutton, namely (i) '**present is key to the past**', and (ii) '**no vestige of a beginning, no prospect of an end.**' The principle of uniformitarianism states that *'the same physical processes and laws that operate today, operated throughout geological time, although not necessarily always with the same intensity as now'* (Hutton postulated same intensity of processes throughout geological time).

The indicators (clues) of palaeoclimates may be classified on the basis of basic sources as follows :

(1) **Biological Indicators**
- (A) **Floral indicators**
  - (i) fossil remains of plants
  - (ii) fossilized pollens
  - (iii) oxygen isotopes
  - (iv) tree ring growth (dendrochronology))
- (B) **Faunal indicators (evidences)**
  - (i) fossilized animal remains
  - (ii) distribution and dispersals of animals

(2) **Geological Indicators**
- (A) **Terrigeneous ancient deposits**
  - (i) lacustrine deposits (varves)
  - (ii) evaporite deposits
  - (iii) sedimentary deposits (coals)
- (B) **Marine deposits**
  - (i) sea floor deposits
- (C) **Pedogenic indicators**

(3) **Cryogenic Indicators**
- (A) **Glaciation**
  - (i) ice ages
  - (ii) glaciers and glaciation
  - (iii) ice sheets and ice cores
- (B) **Periglacial evidences**

(4) **Tectonic Indicators**
- (A) **Plate tectonics**
  - (i) pole wandering and continental drift
  - (ii) palaeomagnetism and sea floor spreading
- (B) **Sea level changes**

(5) **Geomorphological Indicators**
- (A) **Morphological features**
  - (i) erratics
  - (ii) sand dunes
  - (iii) river terraces
  - (iv) duricrusts
  - (v) pediments
  - (iv) tors
- (B) **Geomorphological processes**

(6) **Historical Records**
  - (i) flood records
  - (ii) drought records
  - (iii) migration of man and animals

1. Biological Indicators

The fossilized organic remains of plants and animals (i.e. organic residues) provide significant evidences and proxy data for contemporary climatic conditions mainly temperatures and moisture. It may be mentioned that the nature and types of organisms and their habitats are determined by a climatic type. After their deaths the plants and animals are preserved in the forms of fossilized organic remains in the contemporary and subsequent geological formations. The analysis of such organic fossils through the application of proper techniques (e.g. carbon dating, oxygen isotope analysis, pollen analysis, dendrochronology etc.) reveals important clues to decipher contemporary past climates. The biological indicators fall under two broad categories e.g. (1) plant (floral) indicators, and (2) animal indicators (faunal indicators).

(1) Plant (floral) Indicators

Presently, there is very close correspondence between the distribution of climate types and vegetation types. Based on the principle of **uniformitarianism,** as stated above, and the concept of '**present is key to the past**' it may be opined that similar relationships and conditions might have prevailed throughout geological history of the earth. Thus, on the basis of fossilized plant remains, the vegetation type is inferred and such inferred information (proxy data) provide clue to determine the nature of climate. For example, the existence of coals having remains of tropical forests, in the north-west Europe and Great Britain remind us hot and humid climate of these areas during Jurassic period. The **plant physiology** gives sufficient information about climatic conditions. For example, the fossil remains of plants having long roots, thick barks, waxy leaves, thorns, little leaves etc. indicate warm and dry climate (warm desert climate), while plants having drip leaves are indicators of warm and very moist conditions (tropical rainforest climate). Now question arises, why plant physiology indicates a particular climate? The answer is simple, the physiological characteristics of plants are indicative of their adaptation to particular type of climatic conditions. A few more examples may be cited. The vegetation community having sclerophyllous characteristics (stiff and hard leaves and stems with thick barks) can withstand extreme aridity of summer season. The plant remains of such sclerophyllous vegetation indicate dry summer and wet winter climate (Mediterranean type of climate). The cryophyte vegetations are well adapted to severe cold conditions as they develop such unique features which enable them to withstand extreme cold conditions. Thus, the fossil remains of cryophyte plants indicate cold climatic conditions (tundra climate).

The remains of vegetation in the thick coal seams of Carboniferous period worldover are related to horsetails and club mosses which develop in marsh and swamp environment. The fossil remains of trees in Carboniferous coal seams do not indicate annual ring growth which reveal the fact that such trees thrived in warm and moist climate with no appreciable seasonal contrasts.

Pollen Analysis

The pollen analysis involves the inference of climatic conditions on the basis of dating of fossilized pollen grains preserved in the inorganic sediments layers. It may be mentioned that pollen grains of flowering plants are very durable organic substances which are duly preserved by the nature. The pollen grains are distributed by wind in wide areas having similar type of vegetation. The science of **palynology**, which is the study of pollen grains and spores of plants, helps in identifying the types of vegetation on the basis of pollen grains, and the vegetation types give clues for deciphering the climate in which that vegetation type might have developed. The pollen analysis involves the identification of layered sequence of pollen grains in the terrigenous sediments, the dating of pollen grains of

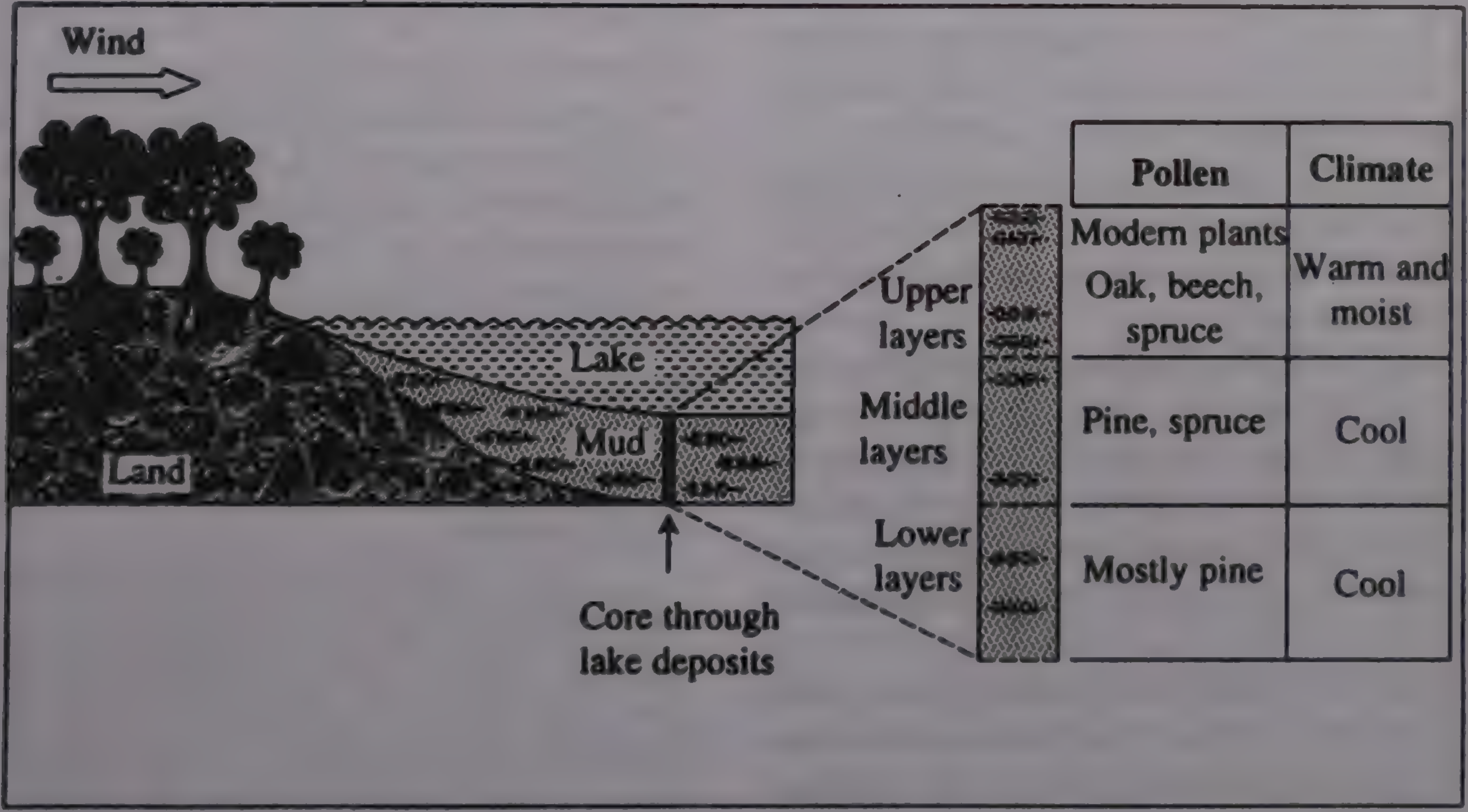


Fig. 14.1 : Presentation of simplified method of pollen analysis for the reconstruction of palaeoclimates. After J.E. Oliver and J.J. Hindore, 2003.

each layer, determination of vegetation type of each layer and finally the determination of climatic condition of each vegetation type (fig. 14.1). Fig. 14.1 depicts the pollen analysis technique wherein the fossilized pollen grains preserved in lacustrine deposits of lower, middle and upper layers denote dominance of pine in the lower layer, prevalence of pine and spruce in the middle layer, and oak, beech and spruce species of trees in the upper layer under the modern plant covers. On the basis of the principle of uniformitarianism, the lower and middle layers having pollen grains of pine and spruce indicate cool climate while the upper layer containing pollen grains of oak, beech and spruce trees reveals the prevalence of warm and moist climate.

It may be remembered that pollens of flowers of plants are blown away by winds, they settle down on land surface as well as water surfaces of lakes, ponds etc. The pollens deposited on land surfaces may decay after lapse of time but pollen grains falling on water surfaces sink down and are deposited in the layers of sediments. The pollens so fossilized in different sedimentary layers are identified and their plant species are determined. The identification of plant species on the basis of their pollen grains then helps in determining the climatic conditions on the basis of present relationship between plant types and associated climatic conditions.

Inspite of wide use of pollen analysis technique in determining vegetation types and associated climatic conditions this method suffers from the following shortcomings.

- In the case of mixed vegetation area having several plant species, the pollen grains are mixed and in such circumstances it becomes difficult to separate pollen grains of dominant and co-dominant plant species and hence this technique fails to give desirable result.
- The winds can carry the pollen grains and deposit them in distant places away from the area of the vegetation of which the pollens have been blown away.
- Not all the pollens of vegetation of a region are deposited, rather they are deposited selectively and randomly, and hence they may not be taken as representatives of particular vegetation type.
- The distribution of vegetation has been tempered and modified by human actions, both advertent and inadvertent and hence pollen analysis would not be useful for the reconstruction of climates of recent past mainly since the neolithic times.
- 'A vegetation cover only attains maturity after fairly a lengthy period of time, and it is quite feasible that the vegetation established through pollen analysis represents successional stage that is not totally representative of the prevailing climate' (Oliver and Hidore, 2003).

Dendrochronology

Dendrochronology is the science that deals with 'the study of the annual rings of trees in determining the dates and chronological orders of past climatic events'. The ring growth of the trunk and stem of a tree provides significant clues for detecting seasonal rhythms of climate during the life time of the concerned tree. The thickness and spacing, and colour of growth rings indicate the climatic conditions and rate of annual growth of trees. The widely spaced thick growth rings denote warm and moist climate with sufficient rainfall to support luxurious and quick growth of trees, while narrow and closely spaced tree growth rings denote arid climate and poor growth of trees. The colours of growth rings also denote seasonal weather conditions. 'The abrupt change from light to dark-coloured rings (growth rings) delineates the annual increments of growth' (*Oliver* and *Hidore*, 2003). It may be mentioned that the study and interpretation of different aspects of tree rings such as, the size (thick or narrow), number, colour shades, symmetry or asymmetry etc. provide information about climatic and environmental variations sustained by the concerned tree during its life time and hence the climatic events which happened in the recent past, say 3000-4000 years before present may be reconstructed on the basis of dendrochronological characteristics.

The study of tree ring growth, known as dendrochronology, was initiated by A. E. Douglas and his team at the University of Arizona, USA. After the analysis of growth rings of trees in the southwestern USA he found close relationship between annual amount of rainfall and growth rings in the adverse climatic conditions of the S. W. United States. The scientists have become successful in reconstructing the climatic conditions and environmental changes for the last 3000 years on the basis of analysis of growth rings of living trees, and for the last 5000 years on the basis of fossils of dead trees. The scientists at the Laboratory of Tree Ring Research, University of Arizona, USA, have also derived logical and fruitful inferences about the relationship between weather elements (e.g. temperature, air pressure, and atmospheric circulation patterns) and widths and spacing of tree rings. Such relationships have also been used to demonstrate climatic fluctuations which took place during the life time of trees.

Dendrochronology also helps in reconstructing the advances and retreats of glaciers in the recent past on the basis of shapes of tree growth rings like concentric (symmetrical) growth rings or asymmetrical rings. It may be remembered that growth rings become concentric and symmetrical as long as the trees remain perfectly erect (perpendicular to the ground surface) but become asymmetrical when the trees are tilted. It is argued that trees are erect when the glacial ice is away from the position of trees but they are tilted when ice comes close to the trees. Thus, erect trees and resultant concentric and symmetrical growth rings are indicative of withdrawal or retreat of glaciers while asymmetrical rings reveal advancing glaciers. It may be mentioned that tilting of trees and resultant asymmetrical growth rings may not be always due to glacial advancement, rather it may also be due to landslides, gusty winds, strong storms etc.

(2) Faunal Indicators

Identification and analysis of fossilized invertebrate animal remains embedded in the sedimentary formations provides significant clues about the climatic conditions that existed during the period of their survivals. In this respect the physiological characteristics of fossils of invertebrate animals (without backbones) and their chemistry are of vital significance wherein two techniques are used to determine their age, namely (1) **radiocarbon dating (C-14 analysis),** and (2) **isotope analysis.**

The analysis of fossils of bones of invertebrate animals helps in determining the lithological successions of sedimentary formations containing animal fossils and thereafter the sequences of palaeoclimates are reconstructed on the basis of dating of animal fossils and sedimentary layers. It may be remembered that animal fossils are mostly preserved in the bottoms of oceans, lakes and rivers which provided them suitable habitats for their development and survival. Each species of tiny creature (e.g. foraminifera) survives in certain temperature and moisture condition. After death such creatures are embedded in the mud layers of water bodies. The mass deaths of certain species of micro-organisms take place when the temperature and moisture conditions change and become unfavourable to them. New species of organisms develop in accordance with new temperature and moisture regime. This process continues and fossils of animals are deposited in the successive layers of bottom sedimentary layers of seas, lakes and rivers. After determining the lithological successions, the animal fossils in each layer are identified and their dates are determined on the basis of carbon-14 analysis. On the basis of the principle of '**uniformitarianism**' (the comparison of animals of a particular geological period as determined on the basis of C-14 analysis, with identical animals at present provides the climatic conditions in which they lived on the ground that same physical processes and laws which operate today operated throughout geological periods) the climatic conditions of that particular period is inferred.

The **radiocarbon dating method** or **carbon-14 analysis** requires obtaining of cores of mud layers containing animal and plant fossils from the floors of oceans, lakes, and river valleys and the dating of the fossils is accomplished through the analysis of carbon-14 and carbon-12 contained in the skeletons of the fossilized animals. It may be mentioned that skeletons of dead animals 'contain both ordinary carbon and minute trace of isotope carbon-14. The proportion of carbon-14 to carbon-12 remains fixed while the organism is alive. After it dies the carbon-14 begins to decay; by knowing the ratio of carbon-12 to carbon-14, one can determine the age of the shell' (Oliver and Hidore, 2003).

The **isotope analysis of the chemistry** of skeletons of fossilized animals also helps in determining palaeoclimates on the basis of temperature and moisture conditions which are inferred from the body chemistry of dead animals. Oxygen has three non-radioactive isotopes e.g. O^{17}, O^{18} and O^{16} out of which the first two isotopes are not very common but the last one is common and normal isotope. After the evaporation of water, these isotopes crystallize at different rates in the shells i.e. O^{18} isotope settles down more rapidly than the O^{16} isotope because the latter is lighter than the former isotope (O^{18}). It may be mentioned that the rate of crystallization of oxygen isotope is controlled by temperature. The number of settling O^{18} isotope decreases with increase in the temperature of ocean water. Thus, on the basis of number of oxygen isotopes contained in the shells of dead animals the prevailing temperature at the time of the existence of particular animal is determined. For this purpose again the cores of mud layers from the floors of oceans, lakes and river valleys are taken out, oxygen isotopes of shells of each mud layer are determined, temperature condition for each mud layer is inferred and finally temperatures prevailing at the time of deposition of animal skeletons and mud layers are used to ascertain climatic changes.

Two important research projects, namely **CLIMAP** (Climate, Longrange Investigation, Mapping and Prediction) and **COHMAP** (Cooperative Holocene Mapping Project), were concerned with the study of climatic changes which might have occurred in the recent past on the basis of **carbon-14 analysis** and **isotope analysis** of skeletons of organisms embedded in the mud layers at the floors of the oceans. The CLIMAP studies concentrated on the reconstruction of palaeoclimates of about 1,000,000 years before present, while COHMAP project studied the palaeoclimates of the past 10,000 years only.

The occurrence of large numbers of animal fossils in close proximity of a region denotes the fact that they might have been killed during a catastrophic disasters e.g. advancing ice sheets and freezing, severe droughts, meteoric collision with the earth (as is supposed to have happened during Cretaceous period killing dinasaurs enmass) etc. On the basis of such evidences one can infer the climatic and environmental conditions at the time of concerned catastrophic disaster.

2. Geological Indicators

Geological indicators (evidences) of palaeoclimates include lithological characteristics of mainly sedimentary deposits such as lacustrine deposits (varves), evaporites, limestones and coal seams, marine deposits (sea floor deposits), soil profiles etc. **Varves** are the alternate sequences of layers of fine silts and clays deposited at the floors of lakes and large ponds in such an area which is characterized by alternate freezing and thawing during winter and summer seasons respectively. Thus, the lithological sequences of lacustrine deposits in the aforesaid condition denote periglacial climate. The analysis of annual layers of silt and clay provides an idea of seasonal changes in climate. It may be mentioned that when the surface freezes during winter season, very fine suspended clay particles are deposited in the lakes and ponds but during summer season, when frozen surface thaws (melts), silts with melt water are deposited in the lakes and ponds. Such type of annual banded alternate layers of clay and silt denote periglacial climate.

Evaporite deposits, represented by salt deposits, occur when climate is characterized by high temperature and aridity wherein evaporation exceeds precipitation. In such circumstances water is evaporated and salt contents are left behind. It may be mentioned that this happens only when water on land is saline and thus salt is in solution form. So, the massive salt rocks deposited on land surfaces, such as in South-West USA, Germany, Central Asia, North-West India (mainly Rajasthan and Gujarat), denote hot and arid climatic environment.

Limestones ($CaCO_3$) containing calcium carbonates are deposited in tropical warm oceanic water and hence the occurrence of limestones in the regions having cold climates denotes the fact that the concerned region was under tropical warm climate at the time of limestone deposition.

Duricrusts are indurated hardened surfaces of different kinds such as **laterites, silcretes, calcretes, alcretes, ferricretes** etc. depending on the dominance of constituent minerals. Normally, lateritic crusts are supposed to have been formed in hot and humid climate of tropical and subtropical areas and therefore these are indicative of hot and humid climate. Lateritic crusts are predominantly found in Chotanagpur highlands (Patlands of Ranchi and Palamau plateaus of Jharkhand), and over many areas of Deccan plateau (e.g. Mahabaleshwar and Panchgani plateaus of Maharashtra). The presence of lateritic crusts in certain parts of Europe (e.g. U.K. and Germany) clearly demonstrates the fact that these are not the result of the present temperate climate. 'Such crusts are often interpreted as of Tertiary age, or as having been under continuous formation since the end of the Mesozoic. Exposures of silcretes and calcretes similarly are often related to past rather than present climatic conditions' (D. R. Stoddart, 1969).

Cave deposits : throw light on the patterns of palaeoclimate. Scientists have studied the oxygen isotopes of deposits of stalagnites in limestone caves to study the changes in the monsoon patterns mainly in India and China. For example, the scientists of the National Geophysical Research Institute (NGRI) at Hyderabad have studied the stalagmite deposits in the Valmiki cave of Karnool district of Andhra Pradesh to detrmine the monsoon patterns for 1000 years (from 14700 A.D. to 15700 A.D. before present) and the following results were derived :

- Age of stalagmite of Valmiki cave was determined through thorium 230 dating and oxygen isotope analysis of samples of stalagmite deposits at every millimeter interval.
- The result of the study revealed that monsoon became more intense every 50, 80 and 200 years because of ocean-atmosphere changes.

- The study also revealed good correlations between Indian monsoon and East Asian monsoon of China because the results of analysis of stalagmites of 2 caves in China (Holo cave and Dongge cave) were perfectly comparable with the result of Valmiki cave.
- Both, south-west monsoon (Indian monsoon) and East Asian monsoon behaved the same in the past.

Pedogenic criteria used to decipher past climates, include the analysis of palaeosols and fossils of plants and animals therein. The alluvial soils buried in older flood plains give indication of moist climate and the dominance of fluvial processes. The older loessic soils indicate dry climate and the dominance of aeolian process. Even the materials involved in the deposition of loess also give clues for climatic conditions. The extensive loess deposits of China having areal coverage of 774,000 km^2 and thickness of 90 m to 300 m consist of materials blown from the deserts of central Asia while the European loess is example of glacial loess. The American loess, extensively found in Illinois, Iowa, Nebraska etc. is partly glacial and partly desert loess. The datermination of palaeoclimates on the basis of fossil remains in the soils is accomplished through radiocarbon dating and isotope analysis, which have already been explained in the previous subsection on floral and faunal indicators.

3. Cryogenic Indicators

Cryogenic indicators are related to the proxy data from the evidences of glaciation, glaciers and icesheets. The science dealing with glaciation and glaciers is known as **glaciology.** The processes of glaciation and deglaciation provide significant proxy data for climatic changes and fluctuation. The period of widespread glaciation of larger areas of the globe is called **great ice age** which comprises several glacial and interglacial periods. The glacial period denotes onset of cold climate and advance of ice sheets while interglacial periods indicate relatively warmer periods when ice sheets retreat. The geologists, glaciologists and climatologists have identified a few great ice ages (e.g. pre- Cambrian ice age, Carboniferous ice age, and Pleistocene ice age) when major portions of the globe were glaciated and covered with thick ice sheets which are definite indicators of major climatic changes.

Credit goes to European school of geomorphologists and glaciologists for identification and recognition of ice ages. *Louis Agassiz* (1807-1873 A.D.) is given credit for an early start in this precarious field and for the recognition and identification of the presence of ice age during Pleistocene period as he presented his ideas in the year 1840. A host of geoscientists, namely Jean de Charpentier, John Playfair (1815), Venetz of Switzerland (1821, 1829), Esmark of Norway (1824), Bernhardi of Germany (1832) etc., studied different aspects of Pleistocene ice age. The Scottish geologist James Geikie postulated the concept of 'great ice age' in 1894 which is comprised of several glacial periods which are separated by warm interglacial periods. A. Penck and Bruckner identified four glacial periods during Pleistocene ice age e.g. Gunz, Mindel, Riss, and Wurm which were separated by three warm interglacial periods. Similarly, four glacial periods (e.g. *Nebraskan*, *Kansan*, *Illinoin*, and *Wisconsin*) and three interglacial periods (e.g. *Aftonian*, *Yarmouth*, and *Sangman*) were identified during Pleistocene glaciation of North America. Most of Gondwanaland was glaciated during Carboniferous ice age.

The shapes of glaciated valleys, glacial drifts, erratics (glacial boulders), striations etc. provide important clues for climatic changes.

The glaciers and ice layers provide evidences for temperature and precipitation conditions during different phases of ice ages. Advancing glaciers and ice sheets indicate cold phase and lowering of temperature much below freezing point, while retreat of ice sheets heralds increase in temperature and subsequent ablation of glaciers demonstrates onset of warmer climate. The glaciologists have demonstrated the retreat of Alpine glaciers and resultant shrinking in their length and width about 3000 B.C. (i.e. about 5000 ybp, years before present), followed by re-advance of glaciers about 500 B.C. (i.e. 2500 ybp) and again retreat of glaciers. The Alpine and Scandinavian glaciers registered resurgence in the 17th and 19th centuries while they again started to retreat in the 20th century. All these indicate climatic fluctuations characterized by cooling (advance of glaciers) and warming (retreat of glaciers) periods during the past 5000 years in European continent.

Ice sheets and **ice cores** are most significant cryogenic indicators of palaeoclimates. It may be remembered that the ice sheets are formed by the deposition of several layers of ice. The accumulated snow from the annual snowfall is compressed and is changed to ice wherein the air bubbles and atmospheric dusts are trapped. Thus, every year a layer of ice is deposited upon underlying ice layer. It is evident that the great ice caps of Greenland and Antarctica are comprised of numerous ice layers wherein the then climatic conditions have been preserved. Thus, the study of each ice layer provides ample evidence of the weather and climatic conditions at the time of its formation. The drilling into ice caps is undertaken to obtain ice cores for analysis. The following properties of ice layers derived from the ice cores provide proxy data for temperature, precipitation, composition of atmosphere, storminess, volcunic events, atmospheric pollution etc.

(i) thickness of annual ice layers → precipitation

(ii) chemical analysis of annual ice layers → temperature

(iii) air bubbles trapped in the annual ice layers → atmospheric composition

(iv) dust contents trapped in the annual ice layer → atmospheric circulation and storminess

(v) acid content in the annual ice layer → volcanic events

A few studies of ice cores from Greenland ice sheets (namely, Greenland Ice Sheet Project 1 and 2, GISP-1 and 2) and Antarctica ice sheets have revealed sequences of climatic variations for the last 110,000 years and 160,000 years respectively. The analysis of ice cores to obtain climatic records is based on **isotopes** of oxygen (two very common isotopes are ^{16}O and ^{18}O) wherein the ratio of ^{16}O to ^{18}O provides information about the existing environmental temperatures at the time of the formation of annual ice layers. The isotope analysis of ice cores also reveals relationship between global warming and concentration of greenhouse gases (e.g. carbon dioxide, methane etc.), and level of atmospheric pollution caused by anthropogenic sources since the period of industrial revolution. Besides, the concentration of radioactive elements in the atmosphere and their fallout emitted during nuclear plant disasters (for example, Chernobyl nuclear disaster) and testings of atomic devices, can be measured through the analysis of annual ice layers. The ice core analysis also reveals information about the levels of sulphate content in the air emitted from the volcanic eruption. With the improvements in the technologies of obtaining ice cores, studies are carried out to reconstruct the atmospheric conditions mainly temperature variations and climatic fluctuations for the past 200 years or so on the basis of the analysis of ice cores derived from mountain ice sheets in the tropical and subtropical areas.

The **evidences of periglacial features** and deposits found in such areas which at present do not have periglacial environment, indicate earlier periglacial climate of those areas. The term **periglacial** literally means around the ice or peripheral to the margins of the glaciers but now this term is used for both **'periglacial landscape'** and **'periglacial climate'.** Periglacial areas are those which are in permanently frozen condition but without permanent ice cover on the ground surface. The periglacial climate is characterized by mean annual temperature ranging between –1°C and –15°C and mean annual precipitation of 120 mm to 1400 mm (mostly in solid form). Many parts of Europe and South-West USA presently do not have periglacial climate but have relict periglacial features which demonstrate that such areas were under periglacial climate in the past.

4. Tectonic Indicators

The tectonic movements involving plate movements, pole wandering, continental drifts, orogenesis, palaeomagnetism, topographic features etc. and seafloor spreading and sea level changes are significant indicators of palaeoclimatic changes. A. Wegener, a German meteorologist, was primarily concerned with the problem of past climatic changes. It may be pointed out that there are ample evidences, as discussed above, which indicate widespread climatic changes throughout the past history of the earth. Infact, the continental drift theory of Wegener 'grew out of the need of explaining the major variations of climate in the past'. The climatic changes which have taken place on the globe may be explained in two ways as follows :

(1) If the continents remained at their places throughout geological history of the earth, the climatic zones might have shifted from one region to another region and thus a particular region might have experienced varying climatic conditions from time to time.

(2) If the climatic zones remained stationary, the landmasses might have been displaced and drifted.

Wagener opted for the second alternative and postulated the concept of 'continental drift' or 'displacement hypothesis' to explain the global climatic changes on the basis of a number of geographical, geological, palaeontological etc. evidences. The plate tectonic theory as an outcome of post-Second World War advancement (mainly in the 1960s) in geotectonics, the evidences of palaeomagnetism and seafloor spreading have validated the concept of polewandering (shifting of the positions of the poles) which help in the reconstruction of climochronology mainly global climatic changes during Carboniferous and Pleistocene Ice Ages and widespread glaciation.

It has been demonstrated that plate movements during Cenozoic era displaced major continental blocks in the middle and high latitudes in the northern hemisphere and thus such northward displaced continental masses were subjected to the dominance of cold climate resulting into widespread glaciation (such as major parts of North America and Eurasia) during Pleistocene period (known as Pleistocene Ice Age and Pleistocene glaciation). On the other hand, mountain ranges of Tertiary period, formed due to collision of convergent plates and consequent subduction of heavier plate and lateral compression, and high plateaus, became effective barriers in controlling the global atmospheric circulation and generating a few new climatic types such as monsoon climate of South Asia (due to relief barriers of the Himalayas and Tibetan plateau). The investigations regarding the impacts of tectonic movements on climatic conditions have revealed strong relationship between horizontal plate movements leading to seafloor spreading along divergent plate boundaries and orogenesis along the convergent plate boundaries, vertical movement (tectonism) leading to upliftment and subsidence and climate change. The changes in global pattern in plate motions cause changes in climates at global scale.

5. Geomorphological Indicators

The geomorphological processes and landforms resulting therefrom have been directly related to particular climatic type on the concept that each climatic type produces its own characteristic assemblage of landforms and set of geomorphological processes which shape them on the basis of the following themes :

- ➤ Landforms differ significantly in different climatic regions.
- ➤ Spatial variations of landforms in different climatic regions are because of spatial variations in climatic parameters (e.g. temperature, humidity, precipitation etc.) and their influences on weathering processes, erosion dynamics and surface runoff.
- ➤ Quaternary climatic changes could not obscure relationships between landforms and climates.

In other words, there are certain diagnostic landforms which clearly demonstrate climate-landforms relationships.

Thus, on the basis of diagnostic landforms, the inference of climatic conditions at the time of the formation of such landform, is drawn which helps in the reconstruction of palaeoclimates.

The climatogenetic or climatically controlled landforms are identified and differentiated in two ways, e.g. (i) general observation and acquaintance of whole landscape of each climatic region, and (ii) identification of typical or distinctive landforms which represent the controls of particular climate. The typical landforms are, in fact, main tools of climatic geomorphologists which help them in determining climate-landforms relationships in different climatic regions. Such distinctive landforms are designated as diagnostic landforms which include duricrusts, inselbergs, pediments, tors, glaciated valleys, glacial boulders or erratics, sand dunes etc.

Duricrusts are indurated hardened surfaces of different kinds such as **laterites, silcretes, calcretes, alcretes, ferricretes** etc. and are normally supposed to have been formed in hot and humid climate of tropical and subtropical areas and hence they are indicative of warm and moist climate. The presence of lateritic crusts in certain parts of Europe (e.g. U.K., Germany etc.) clearly demonstrates the fact that these are not the result of present climate. 'Such crusts are often interpreted as of Tertiary age, or as having been under continuous formation since the end of the Mesozoic. Exposures of silcretes and calcretes are often related to past rather than present climatic conditions' (*D. R. Stoddart*, 1969).

Inselbergs representing steep sided residual hills are considered to be the representative landforms of hot and arid and semi-arid climates. It is argued that inselbergs are structurally controlled rather than climatically controlled and most of the present inselbergs were formed before Quaternary period, 'hence present climates are not necessarily those in which inselbergs were formed' (Stoddart, 1969). It may be possible that inselbergs might have been formed when the climate was warm and arid or semi-arid which might have changed after their formation.

Pediments, characterized by low-angle rock-cut surfaces surrounding mountains, are also considered to be the representative landforms of warm arid and semi-arid climates. Pediments are also found in a variety of climatic conditions e.g. tropical wet and dry climate, subtropical and temperate climates. A few geomorphologists argue that pediments are structurally and tectonically controlled rather than climatically controlled. L.C. King has opined that the process of pediplanation and pedimentation is universal and occurs in all environmental conditions. In fact, 'many arid zone pediments are clearly polycyclic, developed during the complex sequence of Pleistocene pluvials (period of prolonged rainfall) and interpluvials : Many appear to be being destroyed under present climatic conditions, rather than being formed' (*D.R. Stoddart*, 1969).

Tors, 'one of the most controvercial landforms, are piles of broken and exposed masses of hard rocks particularly granites having a crown of rock-blocks of different sizes on the tops and clitters (trains of blocks) on the sides' (*Savindra Singh*, 1977). Tors have been considered of periglacial origin by J. Palmer and *R. A. Neilson* (1962), of fluvial origin by *D. L. Linton* (1955), whereas *L.C. King* has opined that tors are the result of universal processes of pediplanation in different climatic conditions. In fact, the presence of tors right from the Dartmoor of England through Nicargua to India has complicated the problem of the origin of tors rather than solving it.

It may be concluded that the aforesaid diagnostic landforms are older than Pleistocene climatic changes, so they are definitely not related to present climates where they are found. It may be pointed out that climatic relation of landforms at least in glacial, periglacial and warm desert climates is undoubtedly confirmed. So, such landforms may provide definite clues to reconstruct past climates.

It is an established fact that different geomorphological processes work in different climatic regions because the geomorphic processes originate from the atmosphere and their nature (type, e.g. whether fluvial, or glacial, or periglacial or aeolian etc.) depends on the combinations of

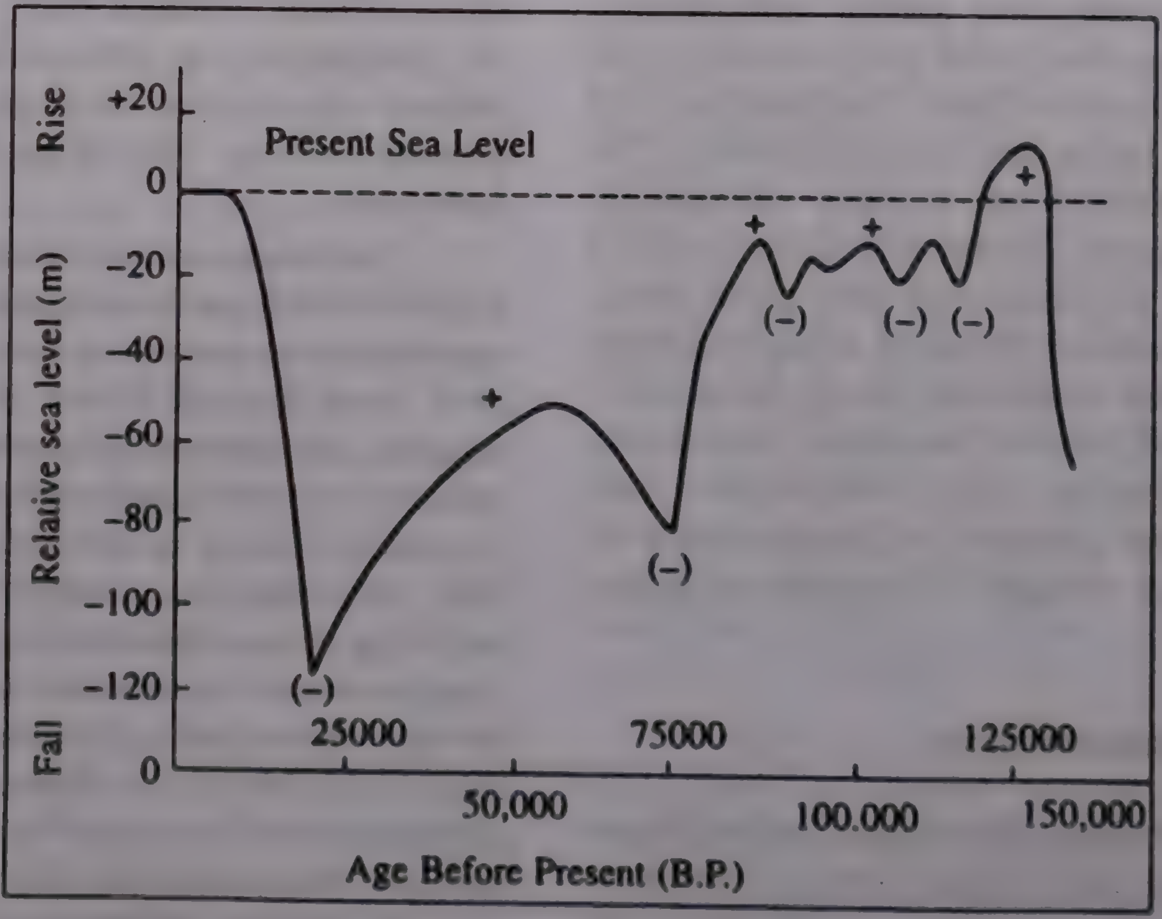


Fig. 14.2 : Fluctuations in sea level during last 150,000 years based on raised coral terraces and core oxygen 18 isotope, data from deep sea deposits. Source : after : K.K. Turekian, 1996, in Oliver and Hidore, 2003.

temperature and precipitation. Thus, the nature of geomorphological processes in the past geological history of the earth helps in deciphering the climatic conditions in which a particular process was predominant.

The presence of glacial boulders or **erratics** in a region presently having other than glacial climate, may it be warm tropical or temperate climate, reminds us the fact that the region was glaciated at the time of formation and deposition of these erratics. Similarly, the presence of frost-riven cliffs, tors, altiplanation terraces, patterned grounds (having stone rings, polygons, garlands, stripes etc.), thermokarst lakes, nivation hollows, involutions, pingos, congelifluctate landforms, blockfields (blockmeers), boulderfields etc. tells us the dominance of periglacial processes under periglacial climate at the time of the development of such landforms. The presence of glacial boulders and erratics in the coal seams of Talcher of Orissa (India) of Gondwana period clearly indicates an earlier cold and glacial climate in India having presently warm monsoon climate.

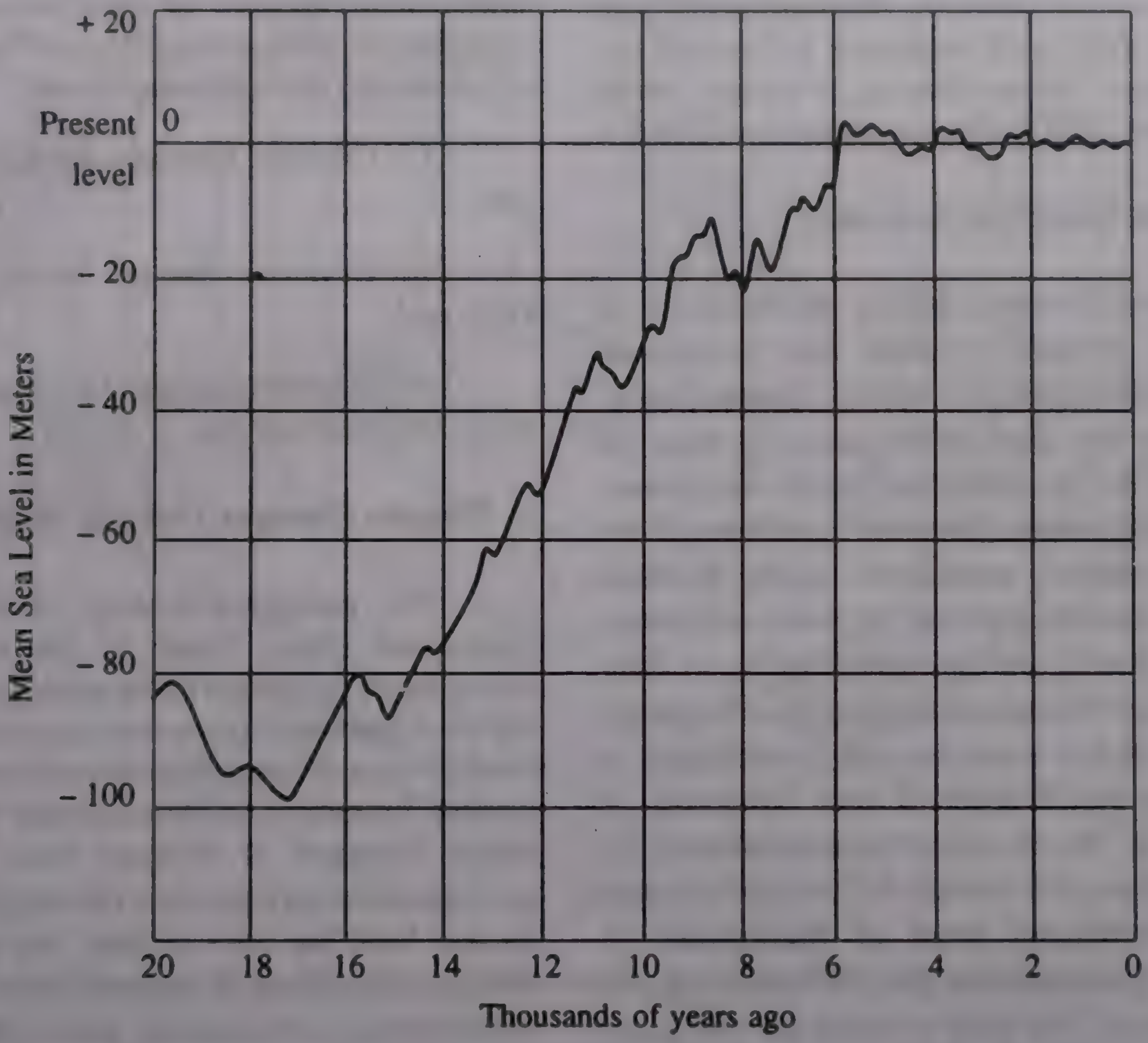


Fig. 14.3 : Fluctuations in sea level with reference to present sea level (present datum line at o meter). Source : after Fairbridge, in H.J. Critchfield, 2002.

6. Sea Level Fluctuations

Fluctuations in sea levels are considered significant indicators of past climatic changes. Sea level changes are of two types, namely **positive change** marked by rise in sea level above datum line, and **negative change** denoting fall in sea level below datum line. Changes in sea level are effected by (i) tectonic movements, and (ii) climatic changes. The tectonic movements cause rise in sea level when there is upward movement of sea floor (ocean bottoms) or down warping of coastal areas whereas fall in sea level is caused by downwarping leading to subsidence of sea floor or upwarping of coastal lands. It may be mentioned that tectonically induced changes in sea levels are very slow. The climatically induced changes in sea levels are rapid and are effected by glacial age and advancement of glaciers and ice sheets (fall in sea levels) and deglaciation leading to retreat of glaciers and ice sheets (rise in sea levels). The sequences of rise and fall in sea levels during Pleistocene Ice Age have revealed several phases of glacial periods (Gunz, Mindel, Riss and Wurm in Europe, and Nebraskan, Kansan, Illinoin and Wisconsin glacial periods in North America and interglacial periods (relatively warm periods) separating two glacial (cold) periods. Figures 14.2 and 14.3 denote fluctuations of sea level (rise and fall) with reference to present sea level (i.e. present datum line at o meter) about 150,000 ybp and 20,000 ybp (years before present).

7. Indicators of Historical Records

The recorded events during the existence of human species provide valuable data for reconstructing the palaeoclimatic history (**palaeochimochronology**) for the past 6000 years. It may be mentioned that the recorded past events are related mostly to extreme events of weather conditions rather than regular weather conditions. Such extreme weather events include freezing of rivers and lakes, unprecedented floods and droughts leading to famines, mass exodus of human migration deserting their settlements etc. A few examples will be sufficient to demonstrate the significance of such indicators of climatic changes. The records of temperatures of the Thames (U.K.) from 9th century A.D. to 18th century A.D. denote increasing trend of frequencies of freezing of the Thames river per 100 years e.g. the Thames was frozen only once or twice per 100 years from 800 to 1500 years ago, 4 times during 16th century, 8 times during 17th century, and 6 times during 18th century. This denotes cooling of U.K. and environs from 800 to 1800 years before present (YBP). The recorded data from Iceland from 900 to 1900 YBP also demonstrate cooling of North Atlantic Ocean between 900 and 1900 YBP. The records of high floods in the Nile Valley since 640 A.D. reveal increase in rainfall in the source regions of the Nile river. The records of droughts in the south-western arid and semiarid United States of America and Sahel region or Sub-Sahara region denote acute deficiency in normal rainfall and resultant extreme aridity.

14.4 RECONSTRUCTION OF PALAEOCLIMATE (CLIMOCHRONOLOGY)

Climochronology may be defined as systematic description of climatic conditions and climatic changes in terms of geological history of the earth i.e. past climates of each period of the earth's history. The reconstruction of palaeoclimates i.e. climochronology means rearranging of climatic history of the globe or part thereof on the basis of indicators/evidences of plaaeoclimates. The description of climochronology of the world may be attempted in the following heads.

(1) Climatic changes during geological periods,

(2) Climatic changes during Quaternary period, and

(3) Climatic changes in the recent past (about past 1000 years or so).

1. Climatic Changes Through Geological Periods

The geological history of the earth or the 'geological clock' refers to the reconstruction of evolutionary sequences of the geological events involving the information of various zones (crust, mantle and core) of the earth, formation and evolution of geomaterials (rocks), formation and development of mountains and faults, evolution of different lives etc. The whole geological history right from the origin of the earth to its present form has been divided into major and minor periods on the basis of forms of life (organic remains), characteristic rock deposits, places of rock formation, major tectonic events etc. The whole geological history of the earth has been divided into five eras (the largest time division of the earth's history has been termed Era) based on five major groups of deposits as follows:

Major Groups of Deposits	**Eras** (from youngest to oldest)
Cenozoic group	Cenozoic (era of recent life)
Mesozoic group	Mesozoic (era of medieval life)
Proterozoic	Proterozoic (era of earlier life)
Archeozoic	Archaeozoic (era of primeval life)

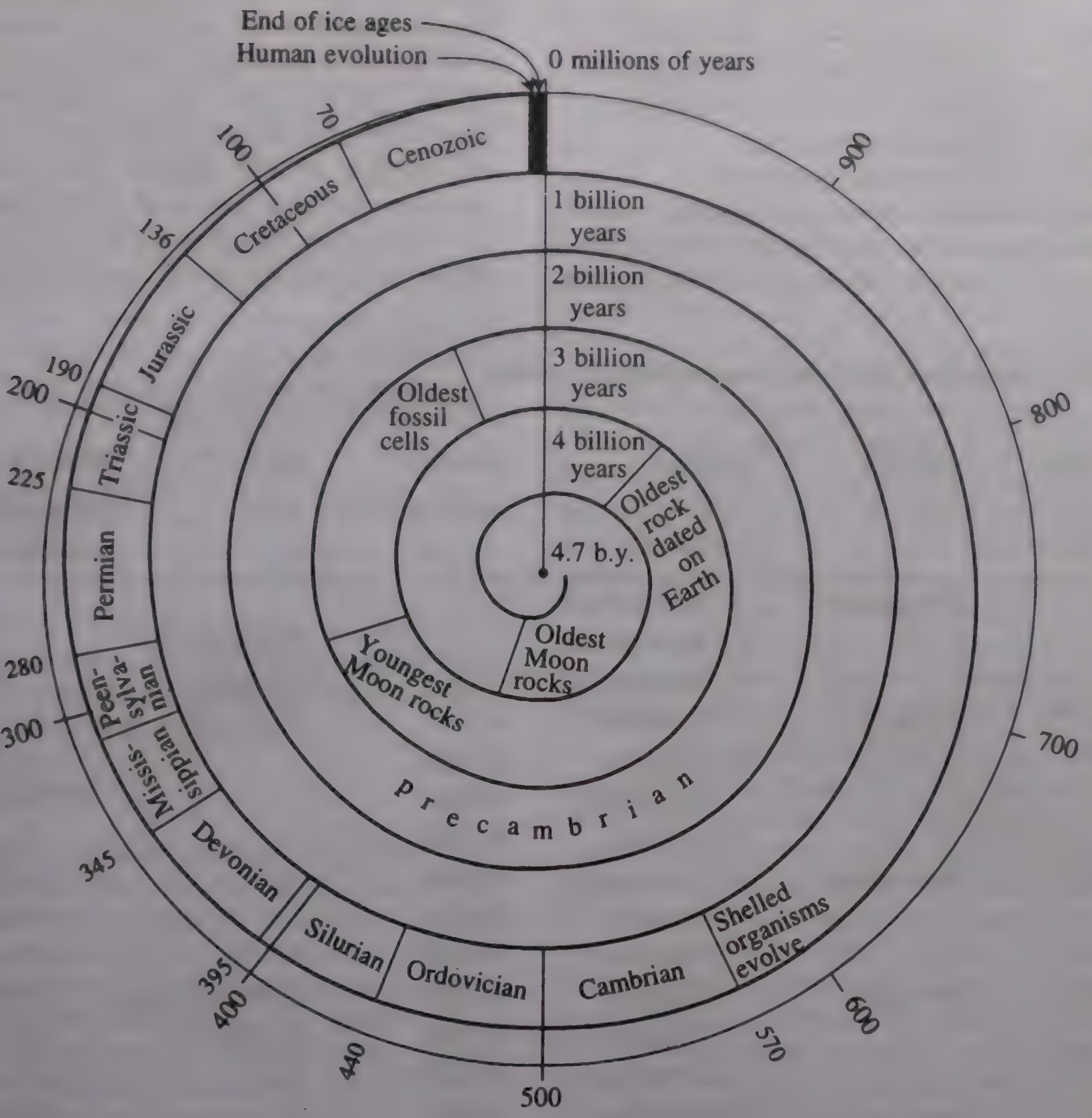

End of ice ages
Human evolution
0 millions of years
70
100
136
190
200
225
280
300
345
395
400
440
500
570
600
700
800
900
Cenozoic
Cretaceous
Jurassic
Triassic
Permian
Peen-sylva-nian
Missis-sippian
Devonian
Silurian
Ordovician
Cambrian
Shelled organisms evolve
Precambrian
1 billion years
2 billion years
3 billion years
4 billion years
4.7 b.y.
Oldest fossil cells
Oldest rock dated on Earth
Oldest Moon rocks
Youngest Moon rocks

Fig. 14.4 : The geological clock (modified after F. Press and R. Siever, 1974). Numbers denote years in millions before present.

Each era is numbered in sequence as first (primary), second (secondary), third (tertiary) and fourth (quaternary) epoch. Further, each epoch is divided into several periods. The names of periods have been assigned on various grounds e.g. names of the places of characteristic systems of deposits, the names of tribes, the characteristics of deposits, dominance of certain elements and minerals etc. as follows :

Palaeozoic	palaeo (ancient), zoe (German)-life
Mesozoic	mesos (German) means middle
Cenozoic	Kainos (German) means new
Cambrian	Cambria or Wales (place) in U.K.
Ordovician	Ordovices (a British tribe in N. Wales)
Silurian	Silurs (a British tribe in S. Wales)
Devonian	Devonshire (place and region in U.K.)
Carboniferous	dominance of carbon (coal)
Permian	perm (a province in erstwhile USSR
Triassic	three-fold division of deposits in Germany, 'trias' means triple
Jurassic	after Jura mountains in Switzerland
Cretaceous	creta (Latin) means chalk, dominance of abundant deposits of white writing chalk

Eocene	Eos means day break
Oligocene	Oligos (German) means little
Miocene	Meion (German) means smaller
Pliocene	Pleion (German) means greater
Pleistocene	Pleistos means most
Holocene	Holo means complete

Some scientists have put together all the geological events of the past history of the earth in the form of a clock. Thus, the spiral system representing the whole geological and geomorphic history together is called as **'geological clock'** wherein one billlion years represent each revolution of the clock's arm. Each revolution is further subdivided into **'hours'** where each division (hour) corresponds to 100 million years and **'minutes'** represent the time period of 10 million years. Fig. 14.4 represents the geological clock suggested by Frank Press and Raymond Siever (1974).

Table 14.1 : Geological Time Table (from youngest to oldest)

Eras	Epochs	Periods	Duration (million years)	Ice Age	Starting time before present (million years)
Neozoic	Quaternary	2. Holocene or			
		Post-glacial		Pleistoecene	
		1. Pleistocene	0.990	ice age 4	1.000
Cenozoic	Tertiary	4. Pliocene	10.000		11.000
		3. Miocene	14.000		25.000
		2. Oligocene	15.000		40.000
		1. Eocene	30.000		70.000
Mesozoic	Secondary	3. Cretaceous	65.000		135.000
		2. Jurassic	45.000		180.000
		1. Triassic	45.000	3	225.000
Palaeozoic	Primary	6. Permian	45.000	Carboniferous	270.000
		5. Carboniferous	80.000	ice age	350.000
		4. Devonian	50.000	age	400.000
		3. Silurian	40.000	2	440.000
		2. Ordovician	60.000	Ice age	500.000
		1. Cambrian	100.000	(450-430 m ybp)	600.000
Pre-Palaeozoic		Pre-Cambrian	-	Pre-Cambrian	700.000
		or Algonican		ice age (850-	
Azoic or Archaean		Archaean	-	600 m ybp)	800.000

Pre-Palaeozoic Era

Very few geological evidences are available to reconstruct the climatic history of early pre-Palaeozoic era. Inferences have been drawn on the basis of lithological evolution and evidences thereof, numerical models and deductions. The earth changed from gaseous state to liquid state after its origin. The solid crust was formed due to cooling and solidification of liquid materials. This phase was followed by the formation of dense atmosphere surrounding the earth. Due to gradual but continued cooling and contraction of the earth and resultant condensation of water vapour there began the precipitation process which ultimately resulted into the development of rivers and seas. It is assumed that the earliest climatic phase of the earth's atmosphere was warm with average (assumed) atmospheric temperature of 37°C about 4250 MYBP (million years before present) which is supposed to have dropped to

25^0C about 2500 MYBP. Such assumptions and calculations are based on the estimate that the concentration of carbon dioxide (CO_2) might have been much higher in the earliest atmosphere than at present and thus the pre-Palaeozoic climate might have been very warm due to **green house effect** of the early atmosphere.

The sequence of warming was broken by many glacial periods as indicated by glacial deposits, a few glacial features, striated surfaces, sedimentary data etc. found from Gowganda, Ramsey lakes, Bruce formations etc. in the Ontario province of Canada. These indicators reveal the existence of probably the **first ice age,** known as **Huronian Glaciation** (on the basis of Lake Huron of Canada and USA) which is supposed to have occurred about 2700 MYBP and might have continued upto 1800 MYBP. The earth again experienced warm climatic phase which continued upto 950 MYBP.

The late pre-Cambrian period is supposed to have been again under cold climatic phase wherein three glacial periods might have occurred when most of the earth's surface was glaciated.

Precambrian Period

The geological characteristics of rocks of pre-Cambrian period which started about 700 MYBP (million years before present) denote that dense atmosphere was formed around the earth. Due to gradual but continued cooling and contraction of the earth and resultant condensation of water vapour there began the process of precipitation which ultimately resulted into the development of rivers and seas. The sequence of warm climate was broken by many glacial periods resulting into the beginning of perhapse the first ice age known as **pre-Cambrian ice age** having a time span from 850 MYBP to 600 MYBP. Among the plant kingdom only marine grasses were evolved. The three pre-Cambrian glacial periods known as Gnejso, Sturtian, and Varangian glacial periods, continued from 950 to 650 MYBP.

Palaeozoic Era (650-600 to 250 MYBP)

The early Cambrian period is supposed to have been in cold climatic phase leading to **ice age** during which the glaciation was more widespread than pre-Cambrian ice age. This cannotation is validated on the basis of the presence of ancient early Cambrian morainic deposits in Greenland, Scottland, Scandinavia, China, South America southern parts of Africa, Australia etc. representing both the hemispheres. This cold phase was followed by warm climatic phase which became responsible for the evolution of life mainly plants in water bodies i.e. seas. Most of the vertebrate animals including 1000 species were evolved in the seas but these are not found at present. These animals depended on marine grasses for their food. Though evidences from ancient organisms and sedimentary deposits suggest warm climatic phase during Cambrian and early Ordovician periods but some evidences from Sahara indicate **little ice phase,** if not ice age, during late Ordovician period. The Silurian period again became warm and this phase continued into Devonian period. The evidences denote warm tropical climate of most of the northern hemisphere including North America, Europe and China, characterized by warm and semi-arid climate. The Devonian period was also characterized by the evolution of green land plants and a large number of species of fish. Amphibians were evolved towards the end of Devonian period. There was dispersal of vertebrate animals from seas to land areas due to such flora on land areas which could provide them food.

The Carboniferous period experienced contrasting climatic conditions in the northern and the southern hemispheres. Most of the coals of North America and Europe were deposited during this period. The northern hemisphere was characterized by warm tropical climate having both warm dry and warm wet climates which became responsible for dense vegetation cover in the northern hemisphere. On the other hand, most of the southern hemisphere, say Gondwanaland, was under cool climatic phase leading to widespread glaciation known as **Carboniferous Ice Age** which is supposed to have continued from middle and late Carboniferous period to early Permian period. The climatic hazard of such widespread glaciation became responsible for extinction of numerous plant and animal species. With increasing seasonal variations in the climatic conditions the ratio of evergreen trees continued to decrease. Consequently, the deciduous trees which could resist dry weather and frost, were evolved. The number and species of land animals further increased and numerous species of mammal-like reptiles were evolved but these soon perished. By the end of Permian period the southern hemisphere recovered from Carboniferous glaciation due to retreat and ablation of ice sheets.

Mesozoic Era (225-70 MYBP)

The climatic condition during Triassic period was warm and dry but it became wet by the end of this period. Consequently, coniferous trees and ferns were developed in the northern hemisphere. For the first time, mammals evolved from reptiles on land areas. The Jurassic climate became subtropical. The rainfall was such that dense vegetation could be evolved and developed in many areas. For the first time, flowering plants (angiosperms) were evolved during this period. Land areas were dominated by forests and swampy plains having lakes and meandering rivers. Cretaceous period was marked by warming of high latitudes which made the growth of vegetation possible upto Greenland. Deciduous trees flourished because of seasonal regime of climate. The **oxygen isotope analysis** of deep sea cores having benthic and plankton fossils (300 planktons) provide ample data for inferring temperatures of oceans in both low and high latitudes. The later half of Cretaceous period witnessed cooling of high latitudes due to northward displacement of land areas of Angaraland. 'This time of earth history saw the world in its **greenhouse mode**, when climate was predominantely warm, polar ice caps nonexistent, and sea level high. The change from this to an eventual **ice house mode** may not have been smooth, but rather episodic' (Oliver and Hidore, 2003).

Cenozoic Era

The early Tertiary witnessed drop in tomperatures but still the climate remained warm. In the **Eocene period** (70 to 40 MYBP) or early Tertiary epoch

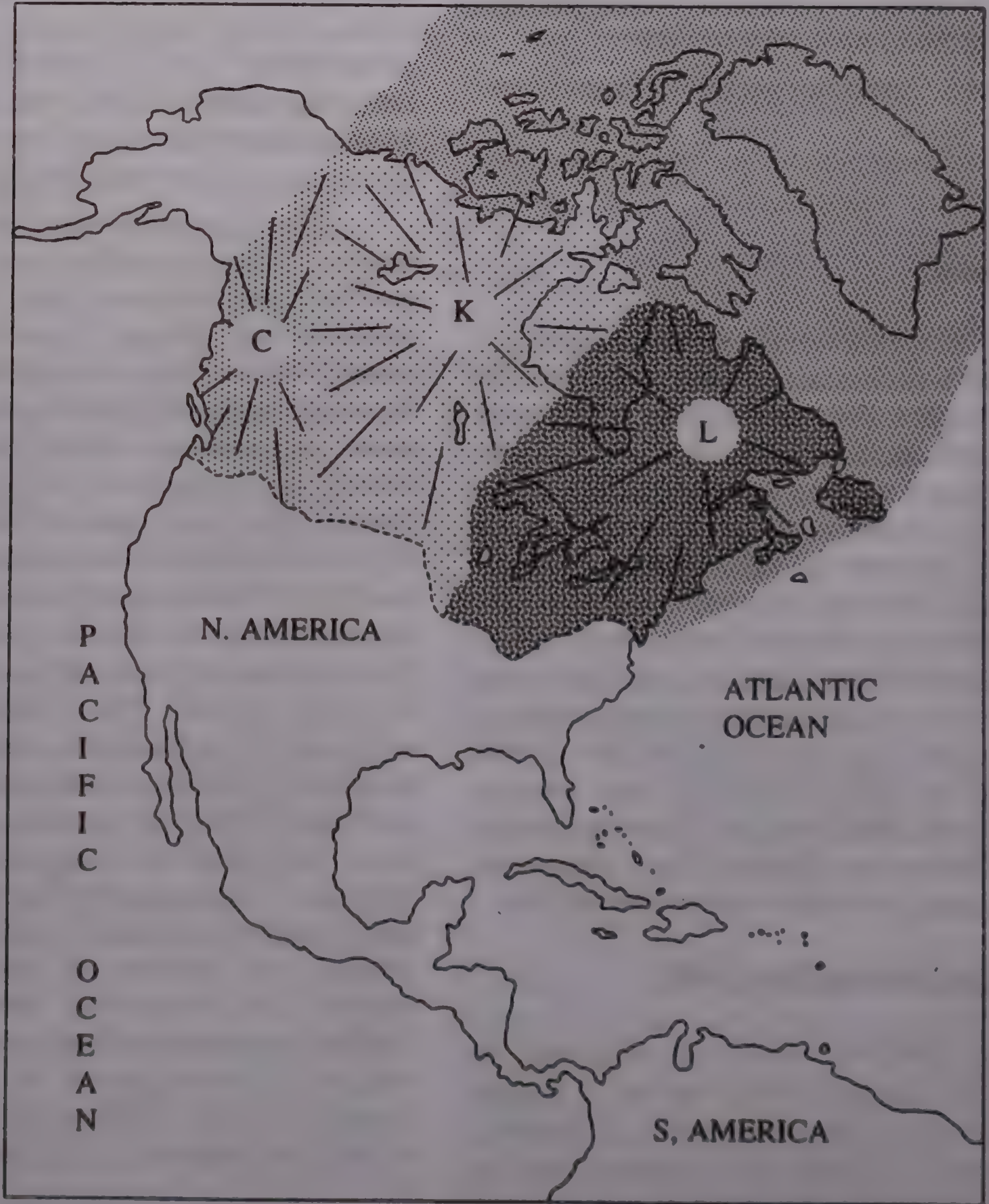


Fig. 14.5 : Glaciation of North America during Pleistocene Ice Age; C-Cordillarean ice sheet, K-Keewatin ice sheet, and L-Labrador ice sheet.

England was characterized by tropical vegetation similar to present Malaysia. Warm climate extended upto Greenland and hence tropical palm trees grew upto Greenland. During **Oligocene period** (40 to 25 MYBP) most of the areas were dominated by warm and temperate climate but the cycle of cold climate also started in this period. The onset of cold climate caused disappearance of forests in some areas mainly in high latitudes but there was expansion in grasslands which became responsible for the evolution of many species of grass eater mammals. During **Miocene period** (25-11 MYBP) the earth's surface was characterized by varying climatic conditions as these varied from dry and desert climatic conditions to wet and cold climate. Humid climate became responsible for the growth and development of deciduous forests having species of maple, oak and poplar in North America and Europe while cedar grew in highlands. The plains of North America were covered by prairie grasses. The **Pliocene period** (11-1 MYBP) witnessed wide range of fluctuations in temperatures i.e. repetition of warm and cold phases. The glaciers began to form over Antarctica. The continued lowering of temperature culminated into the formation of continental glaciation and onset of ice age in Pleistocene period of Quaternary epoch. This is being discussed in the following heading.

2. Quaternary Climate Changes

The Quaternary epoch of Cenozoic era started about one million years before present and continues at present. This epoch comprises Pleistocene and Holocene (post-glacial period) periods. The Pleistocene witnessed most pronounced climatic changes for which much authentic data derived through different techniques such as pollen analysis, isotope analysis, carbon dating, potassium-argan dating etc. are available and the sequences of events are well documented. Major parts of North America and Europe were extensively glaciated during Pleistocene ice age which comprised of four glacial and four interglacial periods.

The Pleistocene glaciation of North America (Fig. 15.5) witnessed four periods of cooling and resultant formation of glaciers and ice sheets and their equatorward advancement. The glacial periods have been identified and named as Nebraskan (300,000-260,000 YBP), Kansan (205,000-167,000 YBP), Illinoin (135,000-100,000 YBP) and Wiscconsin (70,000-10,000 YBP). These four glacial periods were separated by warmer periods, called as interglacial periods, namely Aftonian interglacial period between Nebraskan and Kansan glacial periods (260,000 to 205,000 YBP), Yarmouth interglacial period between Kansan and Illinoin glacial periods (167,000-135,000 YBP), Sangamon interglacial period between Illinoin and Wisconcin glacial periods (100,000-70,000 YBP) and recent Holocene interglacial period. The ice sheets advanced from 3 major sources (ice caps) e.g. (1) Labrador ice sheet; (2) Hudson Bay or Keewatin ice sheets, and (3) Cordillarean or Rocky ice sheets. Two ice sheets of Labrador ice caps and Keewatin ice caps after their initial southward advance combined together and became much wider and extensive ice sheets which moved as far south as upto the province of Nebraska. The combined ice sheets were called as Laurentide ice sheet. The St. Lawrence Valley and central lowland were completely covered by Laurentide ice sheet. Its eastward movement covered the Appalachians. Besides, Alaska, western Canada, Washington, Idaho, Montana etc. were also covered by thick ice sheets measuring 1000 meters to 1500 meters in thickness. The withdrawal or retreat of ice sheets during interglacial periods left behind numerous terminal moraines. Several lakes mainly the Great Lakes (comprising Superior, Michigan, Huron, Erie and Ontario) are the legacy of Pleistocence Ice Age and consequent glaciation.

Table 14.2 : Pleistocene Glaciation of North America

Glacial and Interglacial Periods	Duration (years before present)
1. Nebraskan	300,000-260,000
1. Aftonian (inter glacial)	260,000-205,000
2. Kansan	205,000 - 167,000
2. Yarmouth (inter glacial)	167,000-135,000
3. Illinoin	135,000-100,000
3. Sangamon (inter glacial)	100,000-70,000
4. Wisconcin	70,000-10,000
4. Holocene (inter glacial)	10,000

Europe was glaciated during Pleistocene ice age by the advancing ice sheets from three major sources of snow fields (i.e. caps), namely Scotland, Scandinavia, and the Alps. The advancing ice sheets from Scotland and Scandinavia covered Great Britain, Scandinavian countries, Denmark, Belgium, Luxemberg, Netherlands, Germany while Switzerland, Austria, Italy, France, southern Germany etc. were glaciated by ice sheets advancing northward from the ice caps of the Alps. Like glacial and interglacial periods in North America, four glacial periods have also been identified and named in Europe, e.g. Gunz, Mindel, Riss and Wurm glacial periods wherein two glacial periods were separated by warmer interglacial period. The tropical and subtropical regions of the globe remained warm.

The last but most recent early Wisconcin glacial period started about 70,000 YBP but main Wisconcin glacial period in North America is supposed to have started about 30,000 YBP (years before present) and retreated about 12,000 YBP. The then temperature was about 4°C less than the present temperature.

3. Climate in the Post-Glacial Period

The final retreat and withdrawal of recent ice sheets started about 18,000 YBP and continued upto 10-12,000 YBP when most of the ice covers were withdrawn from the USA. On the other hand, the margins of retreating ice sheets in Scandinavia and Scotland (Europe) started to expand and advance about 10,200 YBP and thus there was reappearance of short period glacial phase involving limited areal extent. This little short-period glacial phase is known as **Younger Dryas** but this temporary glacial phase soon came to an end as the ice sheets melted and finally withdrew. The period ranging from 18,000 to 5,500 YBP is considered as a **period of deglaciation** denoting rapid changes in climate and rise in temperature.

It may be mentioned that the Pleistocene Ice Age caused lowering of sea level at least by 100 meters about 18,000 YBP and the deglaciation during Holocene period resulted in the recovery of sea level to its present level about 5000-6000 YBP (fig. 14.3). As mentioned above after Younger Dryas the warming of previously glaciated areas resulted in complete withdrawal of ice sheets from North America and Europe by 5,500 YBP. Greenland and Antarctica still remained under thick ice sheets. 'All evidence points to this being a time when the mean atmospheric temperature of the mid-latitudes was 2.5°C (4.5°F) above that of the present. This time has been described as the **Climatic Optimum** a term originally applied to Scandinavia when temperatures were warm enough to favour more varied flora and fauna' (Oliver and Hidore, 2003).

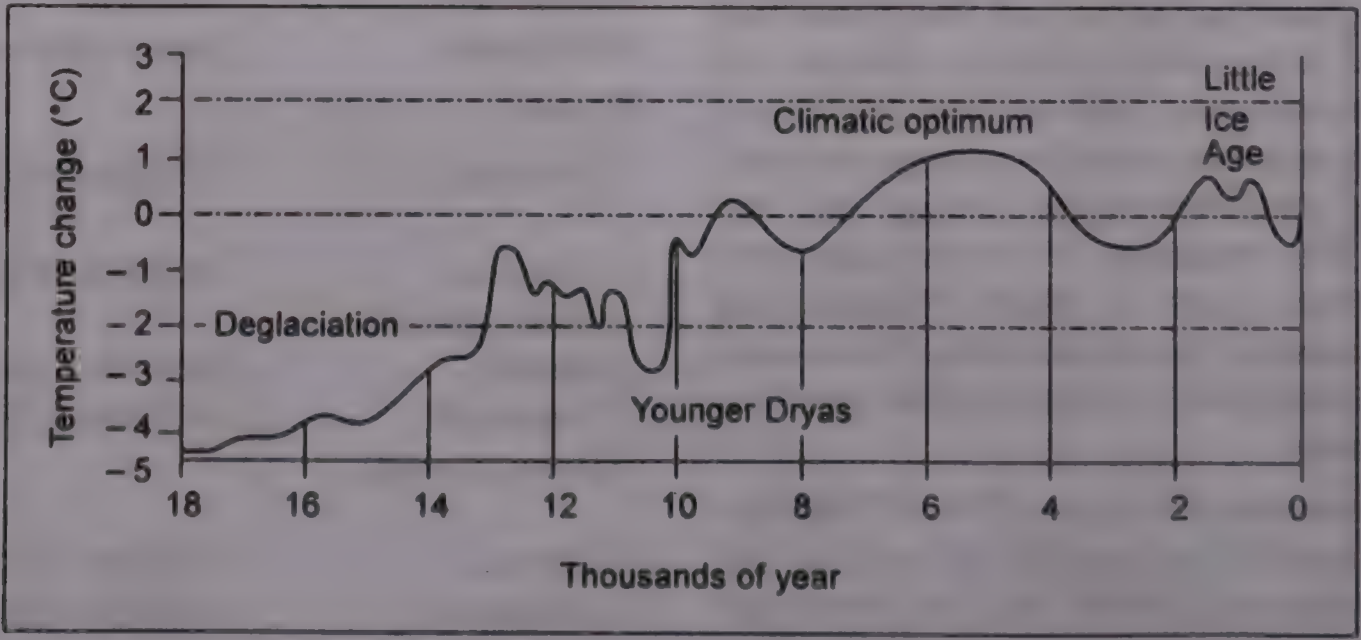


Fig. 14.6 : Trend of changes in surface temperature for the past 14,000 years. The temperature change is from present average global temperature. After J.E. Oliver and J.J. Hidore, 2003.

4. Climatic Changes in the Recent Past (Christian Era)

The proxy data from geological and biological sources and indicators, instrumental records, historical records, documentation etc. provide ample authentic information to reconstruct yearly climatic fluctuations since 1st century A.D. The records show that the temperature and precipitation conditions of European continent and Mediterranean regions were similar to presentday climatic conditions in the 1st century of Christian era. These areas experienced further more humid conditions characterized by increased precipitation and ameleorating temperature upto mid 4th century A.D. (i.e. by 350 A.D.). Europe and North America experienced dry phase resulting into semi-drought condition in the 5th century A.D. The increased aridity caused drying of several lakes in the western USA. The climate in the northern hemisphere became further harsh during 600-700 A.D. when climate became warmer and drier. The increased aridity resulted in melting of valley glaciers in the Alps of Europe and opening of frozen passes allowing free movement of people across the Alpine mountains. It may be mentioned that these passes are again in frozen condition at present time due to reestablishment of valley glaciers. The moist condition returned again in the 9th century A.D.

The period from 950 to 1250 A.D. i.e. 300 year period is called as **Phase of Little Climatic Optimum** in the climatic history of the earth when climate became warm and relatively dry as average temperature increased by 1^0 to 2^0C from the presentday global average temperature. The climate of Greenland and Iceland became mild and attracted the Vikings from Iceland to settle in Greenland. It may be mentioned that Vikings migrated from Europe to settle in Iceland in the 9th century A.D. because of favourable conditions characterized by warmer climate. The climatic conditions in southern Greenland allowed the growth of stunted vegetation, pasture and agriculture to support newly settled human population.

The period from 1250 A.D. to 1450 A.D. was characterized by the reversal of mild climate of 10th to 13th centuries A.D. as referred to above as temperature began to drop causing accumulation of more ice over Greenland, drifting of ice sheets and numerous icebergs in the North Atlantic Ocean. The drifting icebergs disrupted human physical connection of Greenland with Iceland and Europe. The 13th century saw very stormy weather in the Atlantic Ocean and the north Sea while extreme arid condition leading to severe drought prevailed in the western USA.

The trend of worsening climatic conditions in the middle and high latitudes of the northern hemisphere continued and the climate became further harsh for another period of around 400 years (i.e. from 1450 A.D. to 1880 A.D.) as the temperature fell below freezing point giving birth to another glacial period known in the climatic history of the earth as **Little Ice Age.** The climate of Greenland became so cold that the earlier settled people perished and their settlements and other infrastructures were buried under thick cover of ice sheets. The Alpine glaciers became more active, all the glacial valleys were covered with thick ice sheets, the advancing glaciers engulfed several villages at the foot-hills of the Alps mountain chains, several lakes and rivers were frozen, which are presently unfrozen etc. for example, the Thames river of England was frozen 4 times in the 16th century, 8 times in the 17th century, and 6 times in the 18th century. The historical records and Icelandic sagas very much indicate the severity of climate in Iceland. Extreme cold condition led to human deaths due to severe famines. It may be mentioned that glacial period (i.e. Little Ice Age) from 1450 to 1880 A.D. was not always characterized by continuous extreme cold condition and advancing glaciers rather it was punctuated by several cold and warm intervals. It is believed that each cold period continued at least for 30 years in each century (between 15th and 19th centuries) and two cold periods were separated by relatively warm period. The coldest period culminated in the year 1876 when major parts of northern Europe and the USA did not experience summer season. The year 1816 is known as '**the year without a summer**' in the climatic history, when the glaciers became most active after Pleistocene Ice Age, thereafter climate began to improve due to rise in temperature and by the end of 19th century the ice age was terminated.

The records of global temperatures since Industrial Revolution (1860) denote slow but irregaular trend of rise of temperature i.e. ranging between 0.3^0C and 0.6^0. Following R.G. Barry and R.J. Chorley (2002) the phases of rise in temperatures after 1860 have been identified as follows:

- Highly irregular trend of rise in temperature ranging between 0.2°C to 0.4°C between 1860-1920 A.D.
- Consistent trend of rise of temperature of mean value of 0.4°C between 1921 and 1945.
- Oscillating trend of rise of temperature between 1946 and 1975 A.D. around 0.4°C. The northern hemisphere was warmed while the temperature in the southern hemisphere remained more or less constant i.e. neither increase nor decrease.
- Overall warming trend continued between 1976 and 1989 A.D. when temperature registered an upward rise by 0.2°C.
- The global rise of temperature reached its peak in the last decade of 20th century (i.e. 1990s). Six out of seven warmest years on record occurred since 1980.

It may be summarised that overall increase in the surface air temperature in the 20th century has been about 0.5°C to 0.7°C against an average rate of increase of 0.3°C per 1000 years at global level. According to another view the average air temperature in the northern hemisphere increased by 0.4°C between 1880 and 1940 because of rapid rate of combustion of fossil fuels during this period but the temperature dropped after 1950 inspite of continued rapid rate of combustion of fossil fuels due to fast industrial growth but soon after 1940 air temperature in the southern hemisphere showed rising trend which registered an overall increase of 0.6°C between 1940 and 1960.

Another source has indicated an increase in air temperature by 1.5°C upto 1995 while other sources have shown general air temperature rise ranging between 0.3°C and 0.6°C. It may be mentioned that a rise of 2°C temperature from the normal temperature was recorded in the Indian Ocean during 1997-98 which caused catastrophic **coral bleaching** leading to 70 per cent death of corals in the Andman Nicobar and Lakshwadeep inlands.

Various models have been developed to predict global rise in air temperature. S.H. Schneider (1950) pointed out that the temperature could rise upto 1.5°C to 3°C if the concentration of atmospheric carbon dioxide could be doubled from the 300 ppm (by volume) level to 600 ppm. The General Circulation Model (GCM) developed by S. Manabe and R.T. Wetherald (1975) predicts that if the present amount of carbon dioxide (1975 level) of the atmosphere is doubled, the temperature of the earth's surface wil increase by 2.9°C.

The major sources and processes of global warming, for example, ozone depletion and greenhouse gases, will be discussed in the succeeding chapter.

14.5 CAUSES AND THEORIES OF CLIMATIC CHANGES

As mentioned earlier climatic changes are effected by changes in atmospheric circulation and interactions among five components of the earth-atmosphere system, namely atmosphere, hydrosphere, lithosphere, biosphere, and cryosphere (frozen surface of the earth) wherein the amount of received solar energy, and the process of distribution, redistribution, and absorption of solar radiant energy at the earth surface are important considerations of the state of climate of an area in specific time period. The causes for such interactions leading to climatic changes are related to (1) **outside sources,** say **extraterrestrial sources,** and (2) **inside sources,** say eath-atmosphere system or **terrestrial sources**

The causes and theories of climatic changes are viewed in terms of periodicity of climatic changes which are generally of two types, namely (1) **short-term climatic changes,** and (2) **long-term climatic changes.** Since the nature and patterns of climatic changes vary temporally and hence the causes of such changes are also of varied nature. This is why no single theory can explain all types and patterns of climatic changes and thus we have a host of causes and theories of climatic changes.

Since the Industrial Revolution (1860 A.D.) the man's increased economic activities and the application of advance technologies are introducing significant modifications and changes in climatic conditions. This has led to the emergence of a new dimension in climatic changes and an additional source thereof. Thus, the sources of climatic changes may be grouped in the following 3 broad categories :

(1) Outside or extra-terrestrial sources

(2) Inside or terrestrial sources

(3) Anthropogenic sources

The significant causes and related theories of climatic changes may be stated as follows:

(1) Solar irradiance (variation in solar radiation),

(2) Sunspot cycles,

(3) Astronomical theories (ecentricity of earth's orbit, obliquity of the ecliptic, precession of the equinoxes, earth-sun relationship) etc.,

(4) Atmospheric dust hypothesis (mainly volcanic eruptions and dusts thereof),

(5) Carbon dioxide hypothesis,

(6) Continental drift and pole wandering,

(7) Tectonic and topographic control theory,

(8) Oceanic variation hypothesis,

(9) Extra terrestrial bodies collision theory, and

(10) Anthropogenic sources (changes in the earth's surface and atmospheric composition).

Solar Irradiance Theory

Solar radiative forcing is considered to be a significant factor of climatic changes. It is important to note that there are fluctuations in the energy radiated from the sun's outer surface (photosphere). It may also be mentioned that the amount of solar energy received at the earth's surface determines the nature and pattern of energy exchanges and atmospheric circulations which in turn determine temperatures and precipitation. The amount of solar radiant energy received at the earth's surface is also subject to changes due to (i) changes in the composition of the atmosphere in terms of its transparancy to incoming shortwave solar electromagnetic radiation waves, (2) changes in the relative distances between the sun and the earth, (3) the amount of the energy radiated from the earth's surface, (4) changes in the surface covers of the earth's surface etc. The variations in solar irradiance are viewed as (i) long-term change, and (ii) as short-term or periodic change (i.e. sunspots cycles).

It is a common belief that increase in solar radiation for longer duration will cause warming of the atmosphere leading to onset of warm climate and melting of ice sheets and glaciers. It may be mentioned that regular measurement of temperatures of the sun's surface started at the Kitt Peak National Observatory in Arizona, USA, from 1975. It is believed that even 0.1 per cent decrease in the average annual solar radiation for a decade in continuation may introduce measurable climatic changes in terms of changes in temperature and precipitation. The recorded data of sun's surface temperature revealed a drop of temperature by 11^{0}C in January, 1977. If the solar radiation drops by even one to two per cent, the temperature at the earth's surface in the middle and high latitudes may come down and may cause climatic changes similar to Little Ice Age which occurred from 1450 to 1880 A.D. The year 1816 was known as the **year without summer** in the USA. The computer model has further revealed that the drop in solar radiation by 2-3 per cent for 50 years in continuation may cause regeneration of glaciation and may reactivate older glaciers, and if the solar radiation decreases by 5 per cent or more, the earth may experience new ice age and widespread glaciation.

The expansion and contraction of the core of the sun has been accepted by a few scientists as basic cause of changes in the amount of energy radiated from the outer surface of the sun. According to E.J. Opik the core of the sun expands after long intervals. The sun consumes a portion of its energy to expand its outer surface to cope with the expansion of its core. In such circumstance the radiant solar energy decreases because of consumption of substantial portion of solar energy by the sun itself. The decrease in solar radiation results in lowering of atmospheric temperature of the earth and consequently cool phase of climate is introduced, which causes ice age. Conversely, when the core of the sun contracts, the internal consumption of solar energy is remarkably reduced. Consequently, the solar radiation increases, which results in the increase of temperature of the earth's surface, termination of glacial period and beginning of interglacial period.

Simpson Theory

Contrary to the general view of the warming of the earth's surface and its atmosphere during the period of increased solar radiation, Sir George Simpson presented an entirely different concept related to variations in solar radiation and climatic changes in 1938 A.D. According to Simpson during the period of moderate increase in solar irradiance, the middle and high latitudes will experiencre extension in glaciers and their advances while decrease in solar radiation and resultant decrease in air temperatue would cause melting of ice sheets and glaciers and their retreat, resulting into onset of interglacial period. Simpson propounded the concept of cyclic pattern of increase and decrease in solar radiation. According to him the atmospheric temperature increases with increase in solar radiation. The increase in atmospheric temperature causes increase in evaporation and cloudiness, strong meridional air circulation and increased precipitation in higher latitudes. The precipitation in higher latitudes is in the form of snowfall which allows more accumulation of ice and extension of ice sheets and glaciers. The greater cloudiness during summer season prohibits melting of accumulated snow and ice rather protects the ice cover. On the other hand, during the phase of decrease in solar radiation, the atmospheric temperature decreases, meridional air circulation is weakened, evaporation and precipitation remarkably decreases in high latitudes, melting of ice sheets causes their retreat. 'Thus, paradoxically a lowering of mean atmospheric temperature might cause a recession of ice sheets, whereas temperature increase would lead to their advance. Although the Simpson theory appears not to fit recent instrumental evidence, it is a warning against oversimplified explanations of complex processes' (H.J. Critchfield, 2002).

Sunspot Theory

The sunspot activity has been related to variations in solar irradiance. The increased sunspot activity (increase in the number of sunspots) causes warming of the earth's surface and its atmosphere whereas decreased sunspot activity (decrease in the number of sunspots) causes lowering of atmospheric temperature. Sunspots are darker and cooler areas in the photosphere of the sun. The increased sunspot activity means increase in the number of sunspots while decreased sunspot activity is related to decrease in the number of sunspots. The study of sunspot activity for the last 200 years has revealed cyclic pattern of increase and decrease in sunspot activity. On an average, 11 years cycle has been accepted where as the period of one cycle may be as short as 8-9 years and as long as 16 years. Certain subcycles of sunspot activity at longer period have also been postulated e.g. 35 years cycle, 80 years cycle etc. It has been estimated that the output of ultraviolet radiation from the sun's surface at the time of maximum sunspot activity (maximum number of sunspots) is 20 times more than during the period of minimum sunspot activity. The prolonged period of minimum sunspot activity, called as **Maunder Minimum,** is supposed to introduce cooling of the earth's surface and its atmosphere, whereas the prolonged period of maximum sunspot activity may cause warming. It may be mentioned that perfect correlation between sunspot activity and atmospheric temperature has not been substantiated. It may be that periodic fluctuations in sunspot cycles may introduce some sort of weather changes at shorter temporal scale. 'Repeated studies trying to correlate rainfall with the fluctuation in sunspot cycles have not yet produced statistically significant results' (Oliver and Hidore, 2003).

Atmospheric Dust Hypothesis

The atmospheric solid particulate matters include dust particles, salt particles, pollen, smoke and soot, volcanic dusts and ashes etc. Most of the solid particles are kept in suspension in the atmosphere. It is an established fact that these solid particulate matters (SPM) present in the atmosphere reduce the amount of solar radiant energy reaching the earth's surface by scattering, reflection and absorption of incoming shortwave electromagnetic solar radiation. About 23 per cent of incoming solar radiation is scattered by dust particles and haze, of which 6 per cent energy is sent back to the space while 17 per cent energy reaches the earth's surface as diffuse day light, of course much later. The scattering of incoming solar radiation waves by dust particles when the diameter of such particles is longer than the wavelengths of incoming solar radiation waves, is called diffuse reflection which sends some portion of incoming solar energy back to space while some portion remains in the lower atmosphere.

It is also an established fact that sudden increase in dust particles caused by violent powerful volcanic eruptions reduces the temperature of the earth's surface at its lower atmosphere remarkably and introduces fluctuations in weather and climatic conditions atleast at shorter temporal scale. It may be remembered that the stratospheric temperature increases at the time of greater volcanic activity because most of the scattered, reflected and absorbed energy remain there, but the temperature of the lower troposphere and the earth's surface drops significantly, and it is the temperature of the lower atmosphere that controls weather and climate at the earth's surface. This corollary may be substantiated with a few examples of volcanic eruptions and resultant cooling of the earth's surface and its atmosphere.

(1) There was annihilating violent explosive eruption of a volcano on 27 August, 1883 in Krakatoa island located in the Sunda Strait between Java and Sumatra in the East Indies. The powerful volcanic blast was 9TNT equivalent of about 100 million tons (2×10^{11} pounds). Nearly 20 cubic kilometers (some sources put it 53 cubic kilometers) of fragmental materials, ashes and dusts were thrown in the air upto 32 kilometers in the atmosphere (upto middle of stratosphere), which were later on distributed, due to their fall, on an area of 700,000 square kilometers. The fine dusts were ejected upto 32 kilometers in the atmosphere which produced global decrease in solar radiation received at the earth's surface by 10-20 per cent, there was total darkness in the sky because the dusts and ashes blotted out the sun for several days, the effect of total darkness was observed upto the distance of 150 kilometers from the center of eruption. The ejection of fine dusts and ashes in the stratosphere and their circulation and drifting around the earth by upper air atmospheric circulation produced brilliant red sunsets for several years. The reduced solar radiation received on the earth's surface and resultant drop in temperature matches with cold years from 1884 to 1886.

(2) The violent eruption of Mt. Asoma in 1783 in Japan is correlated with severe cold years of 1784, 1785 and 1786. The exceptionally cold year of 1816 A.D., known as **a year without summer** in the climatic history of the world, followed the famous explosive eruption of Mt. Tamboro in Dutch East Indes in the year 1815. The volume of dusts ejected from the violent eruption of this volcano was so enormous that thick dust veil covered the sun resulting into complete darkness for 3 days in continuation, which extended upto a distance of 500 kilometers from the center of eruption.

(3) The explosive eruption of Mt. Katmai in 1912 in Alaska (USA) ejected about 21 cubic kilometers of volcanic materials and dusts in the atmosphere resulting into 20 per cent reduction in the amount of solar radiation received at the earth's surface. About 2 percent drop in solar radiation was noted at the Mauna Loa Observatory in Hawaii at the time of the eruption of Mt Agung in Bali in the year 1963.

Contrary to the general belief of correlation between major volcanic eruptions and lowering of temperatures, the empirical studies of a few recent volcanic eruptions such as El Chichon eruption of 1982 in Mexico, Mt. St. Helens eruption of 1980 (USA) a few earlier explosive eruptions such as Mount Cosequina eruption of 1835 in Nicaragua show no such correlation. It may be mentioned that the impact of volcanic eruptions in lowering the temperature depends on a variety of factors, numely the penetration of the stratosphere by ejected volcanic dusts and gases, the volume of sulphur dioxide, the amount of dusts etc. If the eruption is very explosive and powerful, the volume of ejected sulphur dioxide is very large, and the amounts of dusts are very high, definitely these materials will reach the stratosphere and will reduce the temperature at the earth's surface and its atmosphere. The ejected sulphur dioxide gas after combining with atmospheric water vapour forms tiny droplets of sulpluric acids. These tiny sulphuric acid droplets remain in the atmosphere for longer period and reflect sizeable portion of incoming solar radiation and thus the amount of solar radiation received at the earth's surface is remarkably reduced resulting into the lowering of earth's surface temperature.

Recently, two evidences related to volcanic eruption and its impact on climate change, namely (1) **Volcanic Explosive Index** (VEI) and (2) **Dust Veil Index** (DVI), have been prepared. It is argued that high VEI would indicate powerful and effective penetration of the stratosphere by volcanic dusts and gases and thereby would cause lowering of temperature. Similarly, high DVI would be indicative of reduction in solar radiation received at the earth's surface and consequent drop in temperature. It may be mentioned that resident period of volcanic dusts and gases is very important factor for glacial climate. If the resident period of volcanic materials is for longer duration i.e. if the volcanic materials remain in the atmosphere for longer period, the resultant lowering of temperature may initiate glacial period. On the other hand, short-term resident period would cause only local effects on weather and climate.

Carbon Dioxide Theory

It is important to note that it is the receipt of solar energy at the earth's surface and absorption of incoming solar radiation and outgoing terrestrial radiation by the atmosphere which has significant control on weather and climate, and the amount of energy received at the earth's surface depends on (1) changes in the composition of the atmosphere, (2) changes in the transparency of the atmosphere, (3) modification of energy in the transit (i.e. flowing through the atmosphere) etc. The changes in the gaseous composition of the atmosphere are effected by both natural and anthropogenic sources. The increase of relative proportion of greenhouse gases (e.g. carbon dioxide, methane, nitrogen oxides etc.) in general and carbon dioxide in particular causes global warming and initiates warm climate while decrease in their relative percentage causes global cooling and helps in initiating cold climate if other factors remain constant. Thus, the carbon dioxide theory states that increase and decrease in temperatures of the earth's surface and its atmosphere is effected by increase and decrease of its (CO_2) relative percentage in the gaseous composition of the atmosphere respectively.

It may be remembered that the increase of earth's temperature by absorbing outgoing terrestrial infrared radiation by certain gases (mainly carbon dioxide) is called **greenhouse phase** of the atmosphere whereas **icehouse phase** refers to lowering of earth's temperature leading to beginning of glacial period. The **greenhouse effect** means 'progressive warming-up of the earth's surface due to the blanketing effect of man-made carbon dioxide in the atmosphere' (Oxford Dictionary). 'In a green house, visible sunlight passes through the glass and heats up the soil warming the plants. The warm soils emit radiation in longer wavelengths particularly in the infrared band. Because the glass is opaque to these wavelengths (long wavelengths of infrared radiation waves), it absorbs and reflects (reradiates back to the soils) the infrared (radiation)' (D.B. Botkin and E.A. Keller, 1982). This mechanism keeps the greenhouse warmer than the outside environment. In nut shell it may be summarized that a greenhouse is a body which allows the shortwave incoming solar radiation to come in but does not allow the longwave outgoing terrestrial infrared radiation to escape. Carbon dioxide and water vapour act as greenhouse in that these allow visible sunlight to reach the surface of the earth but absorb and reflect back (reradiate) the longwave outgoing terrestrial radiation mainly infrared radiation (back to the earth's surface) and thus help in keeping the earth's surface warmer.

The most significant greenhouse gas is carbon dioxide which is released to the atmosphere by burning of fossil fuels (coal, mineral oil and natural gas) for different purposes in various ways, burning of firewoods etc. Deforestation also helps in increasing the concentration of carbon dioxide in the atmosphere. The pre-industrial level of atmospheric content of carbon dioxide was fixed at 280-290 ppmv (part per million by volume) or 0.028 per cent to 0.029 per cent (the base year of the beginning of industrial revoltuion in 1860A.D.) It is also important to note that there are certain natural processes and sources which regulate the atmospheric concentration of carbon dioxide, namely vegetation covers and oceans are major sinks(absorbers and users) of atmospheric carbon dioxide. Deforestation and burning of forests for shilfting cultivation remarkably reduces the use of carbon dioxide by vegetation covers and hence helps in increasing the concentration of carbon dioxide in the atmosphere.

The atmospheric content of carbon dioxide increased from the pre-industrial level of 280-290 ppmv to 350-360 ppmv during 1998, registering an overall increase by 25 per cent from the pre-industrial level. It is believed that the rate of increase of atmospheric carbon dioxide through anthropogenic sources will be accelerated due to uncheked industrial development and increasing urbanization worldover.

Different models have been developed to reveal the relationships between the increase in the concentration of atmospheric carbon dioxide through anthropogenic sources and climate changes but the predictions of these models are very much confusing and contradictory. 'If there is uncertainty in the prediction of carbon dioxide trends, then the predictions of the resulting climatic effects are even more uncertain' (J. E. Hobbs, 1980).

(1) **Schneider Model (1950) :** S.H. Schneider while reviewing the results of various climatic models dealing with the predictions in the change of thermal conditions of the atmosphere and the earth's surface resulting from the increased content of atmospheric carbon dioxide concluded that the temperature could rise upto 1.5C-3.0°C if the concentration of atmospheric carbon dioxide could be doubled from 300 ppmv level to 600 ppmv. He further predicts that increased temperature would cause increase in evaporation and cloudiness which would reduce incoming solar radiation (because of increased albedo i.e. more clouds would reflect more solar radiation back to space). Thus, the reduced solar radiation reaching the earth's surface would

counteract the warming of the earth's surface. It is obvious that such feedback mechanisms negate the impact of greenhouse effect of increased atmospheric carbon dioxide and the whole process of the heating or cooling of the lower atmosphere and the earth's surface becomes highly complicated. Another model envisages cooling of the earth's surface due to enormous increase in the atmospheric carbon dioxide.

(3) **General Circulation Model (GCM)** : The general circulation model by S. Manabe and R.T. Wetherald (1975) predicts that if present amount (1975 level) of carbon dioxide of the atmosphere is doubled, the temperature of the earth's surface will increase by 2.9°C and there will be 7 per cent increase in the activity of hydrological cycle but there will not be any feedback and thus there will not be either increase or decrease in the amount of cloudiness as predicted by S. H. Shneider. In other words, the increase in surface temperature caused by increase in the atmospheric carbon dioxide will not be negated by feedback mechanism and hence increased greenhouse effect would certainly introduce climate change (warming of the earth's surface and its lower atmosphere).

It has been estimated that the overall increase in surface temperature over the past one hundred years (upto 2000 A.D.) has been about 0.5°C to 0.7°C. According to another view the average air temperature in the northern hemisphere increased by 0.4°C between 1880 and 1940 because of rapid rate of combustion of fossil fuels during that long period but the temperature dropped after 1950 inspite of continued rapid rate of combustion of fossil fuels due to fast industrial development after 1960. The air temperature in the southern hemisphere showed rising trend which registered an overall increase of 0.6°C between 1940 and 1960. It is evident that though there is maximum consumption of fossil fuels in the northern hemisphere and consequent increase in the concentration of atmospheric carbon dioxide but the air temperature dropped whereas there is minimum consumption of fossil fuels in the southern hemisphere but air temperature increased. It does not mean that there is no direct impact of increasing carbon dioxide on air temperature rather some other factors might have dominated over the factor of greenhouse effect. It is opined that large amount of volcanic dusts thrown into the atmosphere through the eruptions of Heckla (Iceland) in 1947, Mt. Spurr (Alaska, USA) in 1953, Agung (Bali) in 1963, Mount Taal (Philippinse) in 1965, Mayon and Fernandina in 1968 etc. might have reduced air temperature in the northern hemisphere between 1940 and 1970.

Inspite of contrasting opinions about the impact of increasing concentration of atmospheric carbon dioxide due to greenhouse effect on air temperature it may be conclusively opined that there is definite positive effect of increased greenhouse effect due to increased concentration of carbon dioxide in the atmosphere. The increase in temperature introduces several changes in climatic conditions at local, regional, and global levels as fallows:

(1) According to A.B. Pittock (1972) the change in global mean temperature by a few degrees celcious caused by greenhouse effect would greatly change climate.

(2) Increased temperature due to increased greenhouse effect would cause decrease in precipitation and soil moisture content.

(3) In case of global warming oceans would be required to absorb more and more carbondioxide, this will raise normal level of acidity of the oceans, which would decrease biological activity in the oceans and oceanic plant cover, which ultimately would alter the albedo of ocean surface.

(4) It may be possible that the carbon dioxide concentration in the atmosphere may increase to such an extent that the total atmospheric pressure would increase. Such increase in atmospheric pressure would broaden the absorption bands and increase the opacity of the atmosphere to the outgoing terrestrial radiation which would in turn increase the surface temperature to such an extent that all the atmospheric processes may come to grinding halt.

(5) Recently, **atmospheric black clouds** (ABC), as a result of concentration of pollutants in the atmosphere due to burning of fossil fuels, have been related to unprecedented snowfall in Dubai, heavy snowfall in the lower altitudinal areas of Jammu and Kashmir, Himachal Pradesh and Uttaranchal Himalayas (India) etc. during December (2004) and January (2005).

(4) **Atmosphere-Ocean General Circulation Model (AOGCM)** : If the concentration of CO_2 in the atmosphere rises to 540-970 ppm by the end of 21st century, there would be an increase of 1.40° to 5.8°C in the average temperature of the earth's surface and the atmosphere. This increase of temperature has been estimated on the basis of average temperature of the year 1990-2000 A.D.

Continental Drift and Polewandering

The plate tectonic theory, based on the evidences of palaeomagnetism and seafloor spreading, the result of post-1950 advancement in geophysical researches worldover, has validated the concept of continental drift. It has now been proved that different plates are in constant motion and hence the continents and ocean basins change their relative locations. The plate tectonics have two major implications, namely changes in relative positions of the continents (and ocean basins) due to continental displacement (drift), and origin of mountains of varying heights due to convergence of destructive plate boundaries (the effects of the later on climate will be discussed under the next heading). It is believed that the relative locations of continents in relation to the poles have paramount control on climatic changes. The clustering of continental masses around the pole causes glaciation of major land areas while scattering of continents away from the poles causes deglaciation of the land areas which are places at greater distances from the poles, as 'the primary requirement for the formation of great ice caps is the polar location of continents' (J.E. Oliver and J.J. Hidore, 2003).

A lot of convincing evidences are available for two great ice ages e.g. Permo-Carboniferous ice age, and Pleistocene ice age. It is believed that about 350-250 million years B.P. (before present) i.e. during Carboniferous-Permian periods all the landmasses were united in one landmass which has been named as Pangaea II. Most of the land areas of Gondwanaland (comprising present South America, Africa, India, Australia and Antarctica) clustered around south pole which was located near the present position of Durban in Natal (South Africa). Thus, the south pole was located almost in the middle of Pangaea. Consequently, ice sheets might have spread out from south pole at the time of glaciation and Brazil, southern South America upto Falkland, southern Africa, peninsular India, Australia, Antarctica etc., which were closer to south pole, might have been covered with thick ice sheets. At much later date, these land masses might have parted away due to disruption of Pangaea and consequent movement to present locations because of plate movements, and finally might have experienced deglaciation and termination of Permo-Carboniferous ice age.

The Pleistocene glaciation of northern land areas of the northern hemisphere is supposed to have occurrred around one million years B.P. due to closer location of North American and Eurasian landmasses to north pole. The Pangaea began to break during early Jurassic about 180 million years B.P. and the disruption was completed by 70-100 million years B.P. Consequently, the northern part of North America upto present Nebraska in the south (in USA), Greenland, Iceland, Europe and Siberia were covered with ice sheets during Pleistocene period (about one million years B.P.). As mentioned in the preceding section the Pleistocene Ice Age comprised of four glacial periods separated by four interglacial periods of warmer climate. It may be mentioned that interglacial periods within a comprehensive ice age cannot be explained on the basis of continental drift and plate tectonics. It may also be remembered that glaciers of the Rockies, Alps, Himalayas etc. were more extensive than their present position. The glaciation of high mountains, which were far away from the location of pole also cannot be explained on the basis of plate tectonics and continental drift.

Tectonism and Topographic Controls

It is a commonly agreed fact that topographic factor (relief) plays an important role in shaping weather and climate at regional and global levels. High mountains control temperature and upper air circulation patterns. This is why efforts have been made to correlate ice ages with active tectonism and mountain building, 'as with increasing height of landmasses, the potential for ice formation is greatly increased' (Oliver and Hidore, 2003). The advocates of tectonic theory of ice ages and glaciation have tried to demonstrate close relationship between Permo-Carboniferous ice age and Pleistocene ice age and glaciation with large-scale vertical tectonic movements and orogenesis (mountain building) as these two great periods of ice age and widespread glaciation preceded large-scale mountain building activities. In other words, the Caledonian mountain building was followed by Permo-Carboniferous ice age and late Cenozoic mountain building, leading to the formation of Alpine-Himalayan mountain chains, North American cordillera, upliftment of Tebatan plateau, western North America including Great Plains etc, was followed by Pliocene-Pleistocene ice age when major parts of North America and Eurasia were glaciated. Rudiman and Kutzbach (1989) have also demonstrated such relationships through computer models wherein they used the models with 'no mountains', 'half mountains', and 'full mountains' to predict the patterns of general atmospheric circulation and their impact on producing cool climate to introduce glaciation. The computer models based on 'half mountains' and 'full mountains' during late Cenozoic period predicted colder climate over North America, North-Western Europe, and northern Asia during Pliocene-Pleistocene periods and likely ice age and glaciation. The actual occurrence of Pleistocene ice age after late Cenozoic mountain building validates the prediction of computer models, as 'in general 2 to 4 km of late Cenozoic surface uplift in Tibet and the Himalayan mountains, and at least one kilometer uplift across a broad area of the western North America, including the Sierra Nevada, Basin and Range province, Colorado Pleateau, Rocky Mountains, and the western Great Plains, successfully produced changes in the model climates that are comparable to, although less extreme than, the inferred actual climate changes of the late Cenozoic Era' (A.L. Bloom, 2002).

Vertical tectonic movements leading to origin of mountains and their further uplift results in high reliefs which augment erosional and weathering processes which in turn affect atmospheric carbon dioxide. It has already been stated earlier that decreased content of atmospheric carbon dioxide cools the earth's surface and its lower atmosphere to such an extent that glacial climate is induced. The weathering of rocks has been correlated with climatic cooling. In other words, chemical weathering requires dissolution of atmospheric carbon dioxide. The increased rate of chemical weathering results in decrease in the concentration of atmospheric carbon dioxide and resultant reduction in greenhouse effect, with the result cooling of the earth's surface and its lower atmosphere induces glaciation.

Astronomical Theories

The astromical theories are related to three variables, namely (1) earth's orbital **eccentricity,** (2) **obliquity** (tilt) of the earth's rotational axis relative to the plane of earth's orbit, and (3) **precession of equinoxes,** which determine the amount of solar radiation received at the earth's surface and its temporal variations. The earth's orbital eccentricity refers to a ratio between the elliptical orbit of the earth around the sun and a true circle. It may be remembered that the earth revolves around the sun in an elliptical orbit, thus, the eccentricity of the earth's orbit is derived by comparing the orbital elliptical path of the earth to theoretical circular path.

(1) The **eccentricity** of the earth's elliptical orbit simply means deviation of its elliptical orbital path from true circular path. The present position of earth's orbital path has been shown to be closer to circular path. When the earth's orbit is nearest to a circle, the earth's eccentricity becomes almost zero. It has been demonstrated through measurement for the past million years on the basis of infrared data that variations in the earth's eccentricity take place in cyclic manner. The variations in eccentricity during the past 1,000,000 years have changed between a minimum value of 0.001 to maximum value of 0.054. It takes about 95,000 years for the earth's eccentricity to attain its maximum value of 0.054. This is called 95,000 years cycle or **Milutin Milankovitch cycle** (after the name of Serbian scientist M. Milankovitch). The temporal variations in the earth's eccentricity influence the amount of solar radiation to be received by the earth's surface and also determine the temporal variations in solstices and equinoxes. It has been estimated that the maximum variation in the earth's eccentricity (0.054) 'results in a maximum variation of the incoming annual radiation of only 0.2 per cent of the total over a cycle of about 95,000 years' (Berger, 1988, quoted in A.L. Bloom, 2002).

(2) **The obliquity** of the earth's rotational axis or tilt of the earth's rotational axis 'refers to the angle of the axis (of the earth's rotation) in relation to the plane in which the earth revolves around the sun' (Oliver and Hidore, 2003). The obliquity or tilt of the earth's rotational axis varies temporally between 22^0 and $24^0 27'$. The net angular variation is 1.5^0 which oscillates around mean obliquity value of 23.1^0. The present angle of the earth's rotational axis is 66.5^0 giving an obliquity of 23.5^0 i.e. the tilt angle of the earth's rotational axis with respect to the plane of its orbital path is 23.5 degree. The significance of the obliquity factor lies in the fact that it controls the latitudinal distribution of solar radiant energy and the intensity and duration of different seasons. It may be mentioned that if the obliquity angle is zero (i.e. if the rotational axis of the earth is perpendicular to its plane of orbital circle) the length of day, and night would be of equal duration throughout the year, there would be no seasonality i.e. the same season would prevail throughout the year, and the horizontal distribution of climatic zones would be

static but such situation is not possible because no such evidences could be found in the climatic history of the earth. It has been demonstrated through computer models, and manual calculation by Milutin Milankovitch that there have been angular variations in the earth's obliquity in the past and such variations, though small (maximum value of 1.5^0), are sufficient enough to induce changes in the climatic conditions and its world distribution. The change of the earth's obliquity from the minimum angle value of 22^0 to the maximum value of 24^0 27' takes about 41,000 years. Thus, the complete change in the earth's obliquity occurs in cyclic manner and one cycle is completed in a period of 41,000 years. There is direct relationship between the amount of angular variation of the earth's obliquity and seasonal contrasts i.e. difference of temperature in summer and winter seasons. The smaller the changes in the inclination of the earth's rotational axis (obliquity), the smaller is the change of temperature between summer and winter seasons and vice versa. It may be mentioned that warmer winters induce more snowfall and accumulation of ice due to increased evaporation and resultant condensation, while cool summers taboo melting of ice sheets. Thus, it is apparent that if the temperature difference between summer and winter seasons is minimised and if such condition persists for longer duration, the climate would be cold enough to induce glacial period.

(3) **Precession of equinoxes :** The dictionary (Webster) meaning of precession denotes 'slow, conical motion of the earth's axis of rotation, caused by the gravitational attraction of the sun and the moon, and to a smaller extent, of the planets, on the equatorial bluge of the earth,' while the precession of equinoxes 'refers to earlier occurrences of the equinoxes in each successive sidereal year because of the slow retrograde motion of the equinoctial points along the ecliptic, caused by the precession of the earth's axis of rotation' (Webster Dictionary). In more simple words, the precession of equinoxes may be defined as the time of a year or say the days of the year on which the earth's position is nearest to the sun (perihelion) or farthest to the sun (aphelion) due to varying motions of the earth. Thus, the precession of equinoxes denotes 'the regular change in time when the earth is at given distance from the sun.' '**Climatic precession** is a complex variable with principal periods of 23,000 and 19,000 years. The climatic precessional parameter refers to the time of year when the earth is at perihelion, or closet to the sun, which is now in early January (more precisely 3 January). Climatic precession controls the difference in the length of the seasons and has an opposite effect on each hemisphere' (A.L. Bloom, 2002). In other words, at the time of perihelion position of the earth during northern hemispheric winter, the winters in the northern hemisphere become much longer and 7 per cent more warmer while in the southern hemisphere the summers become much longer and 7 per cent less warm.

Presently, the earth's perihelion position with respect to its distance from the sun is in the northern hemispheric winter. The astronomical calculation denotes that this position will be reversed after about 10,000 years from present i.e. the perihelion position of the earth will change to northern hemisphere summer season, with the result winter season will be more extreme and cold due to receipt of less amount of solar radiant energy. The scientists have made successful attempts in computing the dates of occurrences of perihelion and aphelion positions in the past and have tried to reconstruct palaeoclimates on this basis.

Milutin Milankovitch, a Serbian scientist, manually calculated the dates of occurrences of perihelion and aphelion positions of the earth for the past thousands of years (600,000 years) and presented a mathematical model based on the aforesaid three astronomical variables (e.g. eccentricity of the earth's elliptical orbit, obliquity including of the earth's rotational axis, and precession of equinoxes) to explain the advancement (expansion) and retreat (contraction) of ice sheets during Pleistocene Ice Age. His model or theory is popularly known as **'Milankovitch Theory'** or **'orbital variation theory.'** The earth's orbital variations are known as **'Milankovitch cycles'**. The salient features of Milankovitch theory are stated as follows :

(i) The change of obliquity angle of the earth's rotational axis from 22.1^0 to 24^0 27' (say 24.5^0) is completed in a cycle of 41,000 years. Such variations in the inclination of the earth's rotational axis affect the amount of radiant solar energy to be received at the earth surface, temperature distribution, general atmospheric circulation and seasons.

(ii) The change in the eccentricity of the earth's orbit from minimum value of 0.001 to maximum value of 0.054 takes place in a cycle of 95,000 years. Such variation causes variations in the distance of the earth from the sun which in turn affects the amount of insolation and temperature distribution on the earth's surface.

(iii) The precession of equinoxes in terms of the perihelion position of the earth with respect to the sun is completed in about one-half cycle of 11,000 years duration. It is believed that 'in about one-half cycle or 11,000 years from now, the northern hemisphere winter season will be cooler, and more than 23 days longer than the summer season, because the northern hemisphere winter will occur while the earth moves more slowly from the sun' (Berger, 1978, quoted by A.L. Bloom, 2002). The above view is based on the calculation of past events that about 10,500 years before present the northern hemisphere winter was at the time when the earth was farthest (aphelion position of the earth) from the sun.

According to Milankovitch orbital theory cool summers and relatively warmer winters in the latitudinal zone of 50^0 to 70^0 in the northern hemisphere are prerequisite conditions to induce cold phase of the climate leading to continental glaciation because cool summers prevent melting of annual accumulation of snow while relatively warmer winters induce more evaporation and condensation leading to more snowfall and accumulation of ice sheets.

It may be concluded that the eccentricity of the earth's orbit affects the receipt of insolation at the earth's surface while the obliquity of the earth's rotational axis and precession of equinoxes determine the horizontal (latitudinal) distribution of temperature over the earth's surface and length and intensity of summer and winter seasons in terms of temperature. All such changes and variations induce climatic changes.

It has been argued by the critics of Milankovitch orbital theory of climatic changes that 'the amplitude of the fluctuations of solar energy inferred by Milankovitch theory are inadequate to produce the documented climatic changes of ice ages' (A.L. Bloom, 2002). The advocates of this theory are of the opinions that the aforesaid three astronomical variables, known as Milankovitch orbital variables, have operated throughout past geological periods and may be effective in explaining climatic fluctuations at least during ice ages with minor corrections and improvements. They argue that 'other tectonic, atmospheric, oceanographic, and biological changes of the late Cenozoic Era, also created an environment in which the relatively weak orbital parameters could be expressed as major climate changes' (A.L. Bloom) and may act as **climatic pacemaker.**

15

MAN AND ENVIRONMENTAL PROCESSES

Environmental processes include those physical processes which operate on the earth's surface both internally and externally. The internal or endogenetic processes originating from within the earth fostered by diastrophic and sudden forces, caused by thermal conditions of the interior of the earth and varying physical and chemical properties of the materials of which the interior of the earth has been composed of, introduce vertical irregularities on the earth's surface and create various suites of habitats for biotic communities. The external or exogenetic forces originating from the atmosphere driven by solar energy change the face of the earth's surface through erosional and depositional activities. The interactions between endogenetic and exogenetic processes produce complex sets of physical landscapes which affect the biotic communities in the biospheric ecosystem. These physical environmental processes work through several routes of feedback mechanisms. The actions and responses of these processes vary in scale (both spatial and temporal), frequency and magnitude but the environmental processes follow the principle of equifinality-that is they lead to similar end-forms.

The changes, brought in by the physical environmental processes on the earth's surface, occur in such a way that equilibrium is maintained through negative feedback mechanism if man does not interfere in the natural state of physical environmental processes. Now man has emerged as a very important geomorphic agent and is capable of changing the earth's surface at a much faster rate than many of the natural processes. The development of the concept of **'noosphere'** in the former U.S.S.R. highlights the active role played by the conscious mind of man in changing the physical environment and thus generating a new geological epoch. Thus it is pertinent to study the role of man in changing the environmental processes because these processes affect the energy system, hydrological cycle, chemical element cycle and sediment cycle which in turn maintain unity of biospheric ecosystem.

15.1 HISTORICAL PERSPECTIVE

Though man began to interfere with the natural processes right from the beginning of sedentary life but the impact of man on the environment and its processes assumed greater proportion after **industrial revolution** (1860). Man equipped with modern technologies and advanced scientific knowledge has become a very important factor in changing the environmental processes. The realisation of the impacts of man on environmental processes began even in the beginning of the nineteenth century but G.P. Marsh's book 'Man and Nature' (1864) may be taken as the pioneer work which demonstrates the effects of human activity upon environmental processes and cautions the society against the magnitude of changes wrought by man. The following sentence in the preface of Marsh's book (Man and Nature) illustrates the significance of man's role in changing the environmental processes and physical environment.

> *'The object of the present volume is : to indicate the character and, approximately, the extent of changes produced by human action in the physical condition of the globe we inhabit; to point out the dangers of imprudence and the necessity of caution in all operations which, on a large scale, interfere with the spontaneous arrangements of the organic or the inorganic world; to suggest the possibility and the importance of the restoration of disturbed harmonies and the material improvement of waste and exhausted region, and incidentally, to illustrate the doctrine, that man is a power of higher order than any of the other forms of animated life, which, like him, are nourished at the table of bounteous nature'.*
>
> G.P. Marsh (Man and Nature), 1864

Since the publication of Marsh's 'Man and Nature' in 1864 and the realisation of changes in the environmental processes brought by man as aroused by Marsh no significant contributions could be made in this important theme of man-environmental processes relationship upto the first two decades of the twentieth century because the conceptual approaches throughout physical geography were swayed by evolutionary ideas or concepts probably due to the influence of Charles Darwin's 'Origin of Species' (1859). The application of Davisian model of 'cycle of erosion' in the interpretation of physical landscape, the concept of plant succession in the evolution of plant communities, the concept of the development of zonal soils etc. may be quoted as a few examples to show the dominance of evolutionary concept in physical geography. R.L. Sherlock realised the enormous impact of man's activities on many environmental processes as denudation, subsidence, sedimentation, sea coast changes, circulation of water etc. His book 'Man as a Geological Agent' (1922) and his research paper, 'The influence of man as an agent in geographical change' (1923) clearly demonstrate the role of man in changing and transforming the environmental processes. He differentiated between natural (geological) and anthropogenic denudation and observed that erosion induced by man is much more than by natural processes as is evident from his remarks about the densely populated country like England, 'Man is many more time more powerful, as an agent of denudation, than all the atmospheric denuding forces combined' (R.L. Sherlock, 1922, p. 333).

The rapid rate of soil erosion at local, regional and global scales caught the eyes of G.V. Jacks and R.O. Whyte (1939) who presented a picture of soil erosion at world level through their book, 'The Rape of the Earth' (1939), identified the role of man in accelerating the rate of soil erosion and suggested the need for soil conservation and control measures against soil erosion. The individual approach to emphasise the realisation of man's active role in changing the environmental processes and the face of the earth culminated into collective approach to study the man-environmental processes-relationship in 1955 when an interdisciplinary international symposium on 'Man's Role in Changing the Face of the Earth' was organised at Princeton, New Jersey, U.S.A. The publication of the proceedings of the aforesaid symposium in a book form entitled 'Man's Role in Changing the Face of the Earth' edited by W.L. Thomas in 1956 unfolded the dimension of changes in various environmental processes effected by man before the wider section of scientific communities and paved the way for indepth study of processes and mechanism of changes in the environmental processes induced by man and their remedial measures.

The under-emphasis on the study of man's role in changing the environmental processes till 1950 was because of less attention paid towards the measurement of contemporary geomorphological processes and qualitative assessment of the reconstruction of the effects of palaeoprocesses. Increased enthusiam towards the measurement of contemporary environmental processes since 1950 ushered in a new era of realisation of significance of human activities affecting the environmental processes. H. Wilkinson through his research paper 'Man and the Natural Environment' (1963) demonstrated the powerful impact of human activities (destructive, conservative and creative) on natural environment. E. Felese (1956) emphasised the necessity of the study of anthropogenous geomorphological processes. In his research paper 'Man shapes the Earth' E.H. Brown (1970) also studied the impact of human activities on environmental processes. R.J. Chorley and B.A. Kennedy (1973, Physical Geogrpahy : A System Approach) while introducing system approach in physical geography involving morphological system, cascading system, process-response system and control system asserted that man and his activity operate as regulator in the control system.

K.J. Gregory and D.E. Walling (1981) have summarised the development of ideas concerning the impacts of man on environmental processes and have pointed out four major trends in this field during the decade 1960-70.

➤ The first theme was related to the deduction of the rate of erosion in various areas and the presentation of a comparative picture. S. Judson (1968) estimated the current rate of erosion near Rome (Italy) between 100 m^3 per km^2 per year and 1000 m^3 per km^2 per year as against between 20 m^3-30 m^3 per km^2 per year prior to man's influence on environmental processes. The influence of man on gully erosion (in S.W.U.S.A. by W.M. Denevan, 1967), on fire and floods (in Bow Valley of Alberta, by J.G. Nelson and A.B. Byrne, 1966), on urban climate (the climate of London by T.J. Chandler, 1965), on changes of geographic environment through industrialization and urbanisation (S. Gilewaska, 1964) etc. are few examples to demonstrate the initiative taken to study man-environmental processes-relationship.

➤ The second theme of interest was the investigations of natural hazards/environmental hazards.

➤ The third trend was the initiation of international programmes to study the influences of man on nature and natural processes e.g. I.H.D. (International Hydrological Decade, 1965-74), M.B.P. (Man and Bisophere Programme, 1970).

➤ The fourth trend was the realisation of environmental concern which was reflected in a number of writings e.g. 'Silent Springs' (R. Carson, 1962), 'Man and Environment' (R. Arvill, 1967), 'The Environmental Revolution' (M. Nicholson, 1972) etc.

'One consequence of the 1960's may therefore be seen as the development of specific studies on man's influence on particular processes and sections of environment, accompanied by general conceptual attention accorded to human activity. These developments internal to geography were achieved within an intellectual environment which embraced growing concern for the effects of man in the past and concern for his future, and this provided one of the motivating reasons for the initiation of international research programmes' (K.J. Gregory and D.E. Walling, Man and Environmental Processes, 1981, p. 5). This trend resulted into a number of studies, organisation of several national and international symposia and conferences and publication of a number of research papers, research monographs and books on the impact of man on environmental processes and man-environment relationships e.g. 'Environmental Problems' (I.R. Manners and M.W. Mikesell, 1974), 'Man's Impact on Environment' (T.R. Detwyler, 1971), 'Environmental Geomorphology and Landscape Conservation' (in two volumes, D.R. Coates, 1972 and 1973), 'Urbanisation and Environment' (T.R. Detwyler and M.G. Marcus, 1972), 'Urban Geomorphology' (D.R. Coates, 1976), 'Geography and Man's Environment' (A.N. Strahler and A.H. Strahler, 1976), 'Applied Climatology' (J.E. Hobbs, 1980), 'Environmental Change and Tropical Geomorphology' (Ian Douglas and T. Spencer, 1985), ' Environmental Management ' (L.R. Singh, Savindra Singh, R.C. Tiwari and R.P. Srivastava, 1983), First International Conference on Geomorphology and Environmental Management (Manchester U.K., 1985), International Symposium on Geomorphology and Environmental Management (Allahabad, India, 1987), 'Geomorphology and Environment (Savindra Singh and R.C. Tiwari, 1989), Second International Conference on Geomophology and Geoecology (1989, Frankfurt, Germany) etc.

15.2 MAN'S IMPACTS ON ENVIRONMENTAL PROCESSES

The external or exogenetic environmental processes originate from the atmosphere and are basically related to solar energy which affects the basic elements of atmospheric processes. Fluvial, glacial, periglacial and aeolian processes are controlled by solar energy. The efficiency of environmental processes is determined by the potential energy of the lithospheric reliefs. Man, by affecting solar radiation and thus the heat energy, may affect the processes of precipitation and air circulation which in turn would affect the environmental processes. Weather modifications and climatic change affected by man change and transform the very nature of environmental processes.

15.3 MAN AND HYDROLOGICAL PROCESSES

The influence of human activities, both intentional and inadvertent, on hydrological processes and hydrological cycle has been so immense that this theme was included as one of the major focal themes of the study of the IHD (International Hydrological Decade, 1965-74) and IHP (International Hydrological Programme) launched by the UNESCO. The modifications of hydrological processes by human activities range from local level to regional level including small-scale insignificant to large-scale catastrophic effects.

The hydrological cycle of natural drainage basins has been largely modified by human activities in almost all of the countries. The hydrological cycle of a drainage basin unaffected by man operates in the following manner.

The basic input of the basin is rainfall which is intercepted first by vegetation and reaches the ground as **'aerial streamlets'** or 'stemflow' and throughfall. In the absence of vegetation the rainfall reaches the ground directly. Some portion is lost to the atmosphere through evapo-transpiration. The water available on the ground forms **'surface storage'** of which a sizeable portion moves down the slope as surface runoff, some portion is evaporated, some portion remains on the ground surface while some portion infiltrates downward into the soil to form **'soil moisture storage'** of which some portion is lost through evaporation and plant transpiration, some portion reppears as seepage and springs via throughflow and interflow while some portion percolates downward to form **'ground water storage'** of which some portion reaches the channel through base flow, some portion moves upward as capillary rise to reach 'soil moisture storage' and some portion is routed further downward through deep transfer. The **'channel storage'** receives water from surface storage through surface runoff, from soil moisture storage through interflow and throughflow and from groundwater storage through base flow. Thus the initial input of precipitation finds exit through two paths of output e.g. (i) through evapotranspiration from all types of storages as referred to above, and (ii) through channel runoff from channel storage.

Man affects and modifies the internal processes of hydrological regime of drainage basins in a variety of ways. These modifications have both positive and negative effects. The input of precipitation in the hydrological cycle of a drainage basin is modified through **'cloud seeding'** for induced precipitation (increase in input), atmospheric pollution (both increase and decrease in precipitation input), modified atmospheric circulation (e.g. urbanisation induces vertical convective currents and thus increases precipitation, see section 13.11, chapter 13), forest clearance (decrease in precipitation), vegetation modification (changes in precipitation) etc. The **cloud seeding** was practiced during monsoon period in 2007 in 12 districts of Telangana region of Andhra Pradesh (India) when continuous 75 hours of flying was carried out to sread cloud seeding substances. This led to over 1,850 mm of rainfall. The samples of rainwater were analysed to ascertain the relationship between received rainfall during this period and mechanism of cloud seeding. The analysis revealed calcium concentration ranging from 12 to 36 mg per litre of rainwater, which is a sure indicator of artificially-induced rainfall. Additional input of water on ground surface is provided through irrigation of crops and effluent disposal from urban areas. 'Interception storage' is modified by forest clearance (reduction in interception storage) and vegetation modification. 'Surface storage' is modified by land clearance, cultivation, urbanisation, land drainage, mining etc. while surface runoff is increased due to deforestation and cultivation and is supplemented by additional input through channelled irrigation for cropland and effluent disposal from urban areas. Infiltration is modified through devegetation (decrease in infiltration), urbanisation (decrease), afforestation and reforestation (increase) and irrigation (increase). 'Soil moisture storage' is positively affected by irrigation, planting of grasses and plants, artificial recharge, seepage from water supply systems, soakpits, cesspools etc. while it is negatively affected by land clearance through deforestation, burning of grasslands, urbanisation etc. 'Groundwater storage' is modified through extraction of groundwater for domestic use and irrigational purposes while 'channel storage' is modified through flood plain development, channel modification (shortening or lengthening of channels), river regulation, construction of dams and reservoirs etc. The impacts of man's activities on different components of basin hydrological cycle may 'include increased flood hazard and other changes in river regime, reduced availability of groundwater, deterioration of water quality and widespread eutrophication of water bodies and river systems in response to increased nutrient loadings' (K.J. Gregory and D.E. Walling, 1981).

In the forested area (either natural or man-made) falling rain drops are intercepted by the forest canopy and major portion of rainfall reaches the ground surface through 'aerial streamlets' and stemflow and thus a sizeable portion of rainwater infiltrates into the ground surface and surface runoff is decreased. This process minimises channel flow to assume flood stage on the one hand and increases recharge of groundwater on the other hand. On the

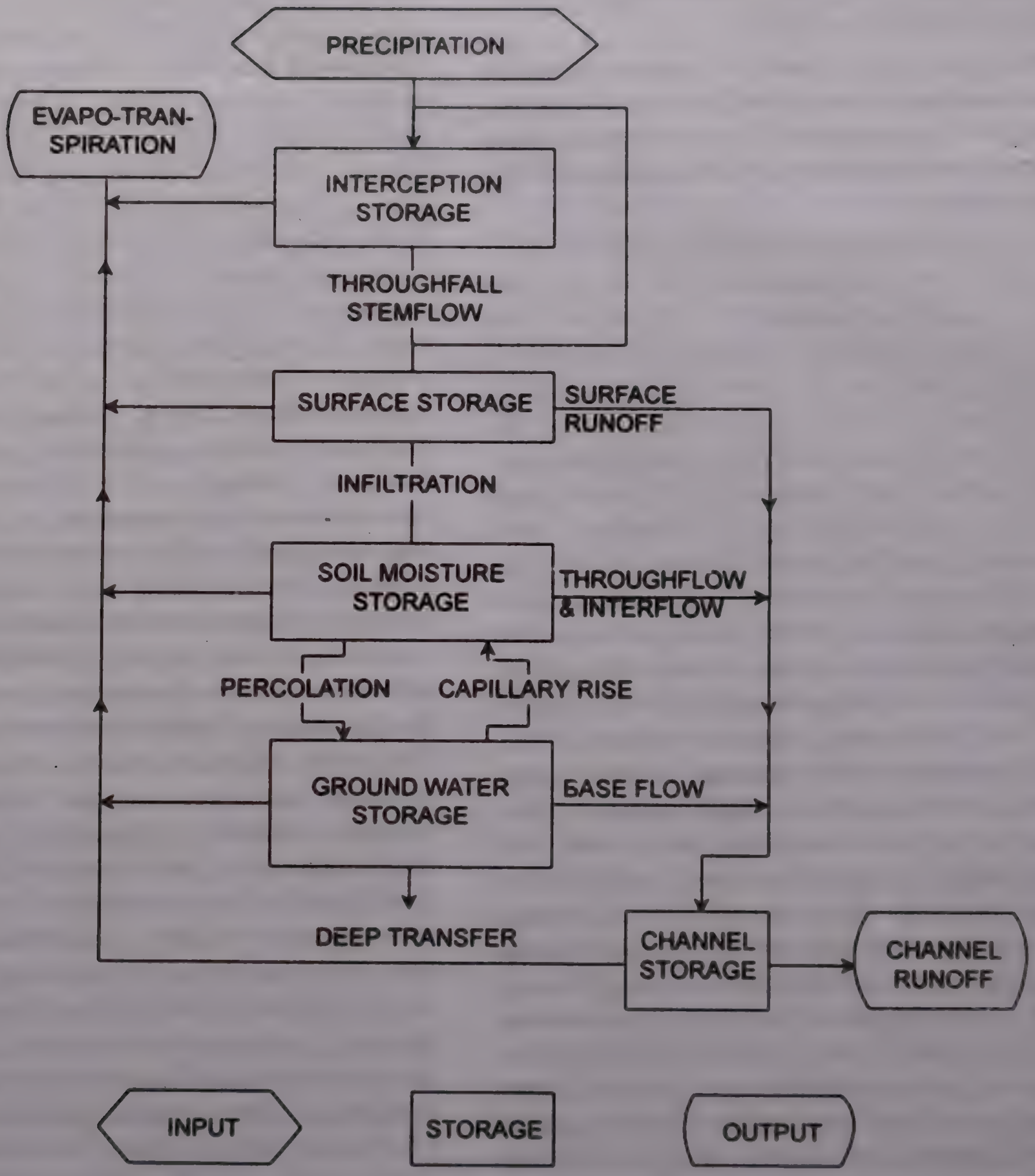

PRECIPITATION
EVAPO-TRAN-SPIRATION
INTERCEPTION STORAGE
THROUGHFALL STEMFLOW
SURFACE STORAGE
SURFACE RUNOFF
INFILTRATION
SOIL MOISTURE STORAGE
THROUGHFLOW & INTERFLOW
PERCOLATION
CAPILLARY RISE
GROUND WATER STORAGE
BASE FLOW
DEEP TRANSFER
CHANNEL STORAGE
CHANNEL RUNOFF
INPUT
STORAGE
OUTPUT

Fig. 15.1 : Natural hydrological Cycle.

contrary, cleared land (devegetaed) receives the rain drops with full kinetic energy directly and thus the loose bare ground surface is heavily pelted by falling rain drops which result in the compaction of loose materials and thus surface runoff is increased but infiltration is markedly reduced. This process leads to increase in channel flow causing floods on one hand while reduced infiltration results in poor recharge which reduces the replenishment of groundwater storage on the other hand.

Urbanisation modifies hydrologic characteristics of drainage basins in two ways e.g. (i) increaseing urbanization results in the increase of pucca (masonry) structure through the construction of buildings, courtyards, pavements, roads, streets etc. and thus there is marked increase in impervious ground surface which reduces infiltration and increases overland flow in the form of surface runoff which reaches the nearby streams and increases flood peaks during rainstorms. Conversely, reduction in infiltration results in marked decrease in recharge of groundwater storage and consequently decrease in base flow contribution to nearby streams causes minimum discharge during dry season of the year. Thus the range of flood stage and minimum discharge during low stage (low water level) is accentuated. (ii) Surface runoff reaches the streams directly through storm drains and sewers very quickly and thus the runoff travel-time is reduced and consequently the lag-time between rainstorms and peak discharge is shortened which results in flash floods in the rivers.

The effects of land drainage (artificial field drains to remove surface water from the areas of intensive farming, commercial forests and waterlogging in the areas of impervious soils) on hydrological characteristics of drainage basins as reported from various studies in different parts of the world have been related to increase in flood because clearance of surface water through land drainage lowers down the water table, reduces evapotranspiration and increases mean annual surface runoff.

Man's activities besides modifying the volume of water (quantity) passing through different interlinked components of the basin hydrological cycle, also modify the quality of water in terms of physical and chemical properties. These modifications may not always be necessarily pollution though water pollution does occur from the used water (domestic, urban and industrial effluents) which reaches the channels. Changes in stream flow quality have been widely reported through the studies of vegetation removal and soil disturbance (through vegetation removal, strip mining etc.). The mineral and nutrient cycles, sediment load and sediment budget of streams are largely modified due to devegetation, excavation (mining) and building activities (construction of dams and reservoirs). These aspects would be discussed in the succeeding section. Salinisation is a perpetual problem in the areas of canal irrigation mainly in the semi-arid zones. The findings of the study of NES (National Eutrophication Survey, U.S.A.) regarding the measurement of relationships between stream nutrient loading and watershed land use in 473 small basins to the east of the Mississippi river (selected from different areas having different land uses e.g. forest, mostly forest, mixed, mostly urban, mostly agricultural and agriculture) revealed a vast difference in the total mean concentration of phosphorous (0.15 mg per litre of water in the agriculture-dominated watersheds and 0.014 mg per litre of water in the forest-dominated basins) and nitrogen (4.17 mg and 0.85 mg per litre of water for agriculture-dominated and forest-dominated basins respectively) which is because of the use of fertilizers in the agricultural watersheds.

15.4 MAN AND WEATHERING AND MASSMOVEMENT PROCESSES

Weathering refers to disintegration and decomposition of rocks and regoliths in situ. Weathering is a natural process and is accomplished through various combinations of insolation, water, frost, air, pressure, oxygen, carbon dioxide, hydrogen, plants and animals. Man being a biological agent acelerates and decelerates the natural rate of weathering. Mining activities for extraction of minerals, blasting of hills and ridges for dam construction and mineral extraction, quarrying for industrial (limestone for cement) and building materials etc. result in such a fast rate of disintegration of geomaterials that this may be accomplished by natural weathering processes in thousands to million of years. Man accelerates the rate of weathering on hillslopes by modifying the ground surface through deforestation. Vegetations mainly trees with high density provide stability to hillslope profiles as the root networks provide mechanical reinforcement to regolith on hillslope and increases cohesion of geomaterials. Deforestation on hillslopes reduces the mechanical reinforcement and cohesion of unconsolidated geomaterials and thus increases slope instability which causes slope failures and mass movement of materials down the slope in the form of landslides, slumping and debris fall and slides. Man-induced landslides due to deforestation have become common features in the foothills of the Himalayas.

Human activities causing mudflow and earthflow mainly fall into two categories e.g. (i) accumulation of waste soil and rock fragments arising out of mining activities into huge piles results in spontaneous lateral earth flow engulfing surrounding areas and (ii) removal of support by undermining of natural masses of soil, regolith and rock (A.N. Strahler and A.H. Strahler, 1976, p. 190). The constructional activities like dams, canals etc. and construction at the base of hillslope leads to removal of support to slope and causes mass movement. Construction of roads along and across hills and ridges composed of weak lithologies (e.g. shales) causes frequent earth flows. Such examples are observable along the Rewa scarps just to the south of the Ganga plain and Kaimur hills (southern margin of the Rewa plateau) which are composed of quartzitic sandstones above and shales below. The roads have been constructed in shale lithology. The steep walls of shales along the road-side very often collapse and minor to major earthflow occurs at many places every year and causes road blocks. Such phenomena are very common features in the Himalayas.

The encroachment of urban settlements on hillslopes affects slope processes and mass- movement of rockwaste. It is significant to point out that safety factor on the higher sides of hillslope is almost close to unity. Any effort through man's activities may destabilise the equilibrium condition and cause slope failure and massmovement.

For example, construction of roads, buildings, laying out of waterpipes and power cables, construction of sewers etc. on higher sides of hillslopes for human purposes decrease the resisting force of slope materials. If the aforesaid works are not properly planned, there result slope failures and hazardous earthflows and landslides are caused. Example may be cited from Nainital (Uttarakhand, India) town which is located on hillslopoes surrounding Naina Lake. The construction of buildings and roads is gradually increasing upslope. The lithologies constist of shales and dolomites. The encroachment of buildings and roads at the cost of natural vegetation has decreased the safety factor which may result in severe landslide any time. It may be mentioned that a very massive landslide occurred in the northwestern side of the lake in 1884 and a sizeable part of Naina Lake was filled with debris. This infilled part of the lake is now used as helipad. It is necessary to measure slope angles, to study lithologies, safety factor, groundwater conditions, nature of soil and regolith before the construction of roads traversing the slopes and houses and other establishments so that hazardous consequences may be avoided.

15.5 MAN AND COASTAL PROCESSES

Sea coastal areas are affected by natural marine processes mainly by sea waves and tidal currents. These waves and currents, of various types, erode the coastal lands and create several erosional landforms (e.g. sea cliffs, rocky slopes, indented and crenulated coast lines, coves and caves etc.) and in turn these waves also deposit materials of various sizes to form beaches and bars. Majority of the coastal features are formed by natural marine processes but man's activities have modified the coastal processes and have accelerated or decelerated erosional and or depositional works of marine waves at certain localities mainly at the sites of harbours and recreation.

The direct modifications of coastal processes by man include the following :

- ➤ disruption of wave motion and weakening of energy of coast-bound waves by injecting air bubble curtains,
- ➤ attempts to deflect or resist the effects of sea waves and currents by constructing sea walls, groynes (groins), break-waters (masonry walls to break sea waves),
- ➤ trapping or import of sediments to replenish beaches, and
- ➤ plantation of trees to stabilise beaches and coastal dunes.

Man's attempts to reduce or stop coastal erosion and therefore to check retrogradation on the one hand and to promote deposition to encourage progradation on the other hand have not been successful because of complex nature of mechanisms of coastal processes, both erosional and depositonal. These direct attempts of man to manipulate and modify coastal processes for specific purposes (to halt erosion at harbours, to build beaches, to replenish already depleted beaches, to open inlets to encourage sea transport etc.) bring in changes in nearshore topography, mechanism of wave and current actions and coastal erosion, nature and pattern of sediment movement and deposition on the adjacent part of the coast where structural works have been initiated.

Protective Structures

Protective structures to check cliff erosion includes the following :

(1) Sea walls

(2) Breakers

(3) Groins

(1) Sea Walls : Protective structures in the form of masonary or concrete sea walls are built to protect the coastal land from wave and current erosion in those areas which have cliffed-coast but the immediate hinterlands are either urbanised or industrialised and are in danger of being eroded by the recession of cliff due to wave attack or the coastal areas are significant resort centres, or there are sites of harbours which are endangered by wave erosion. The construction of sea walls (fig. 15.2) to stop the recession of cliffs at the sites of recreation produces adverse effects on beaches. In such cases beaches are depleted because (i) the supply of sands and shingles from the cliff erosion is stopped due to protection provided by extended sea walls parallel to the coast, and (ii) wave after striking powerfully against the walls scour the beaches and remove the materials.

Basically three types of sea walls are constructed :

(i) concrete sea walls

(ii) wooden sea walls

(iii) boulder sea walls

Boulder sea walls have been used to protect the coasts of Ratnagiri area of Maharastra (India).

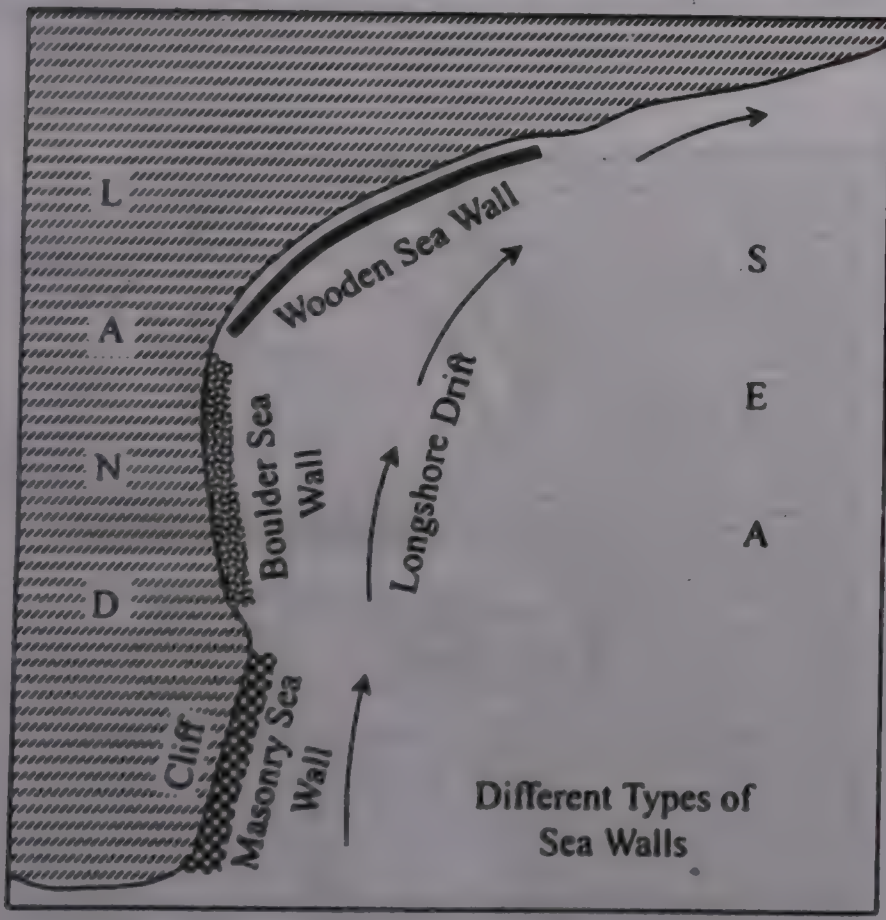


Fig. 15.2 : Construction of concretionary protective sea walls.

Another use of **sea walls** as **dykes** is to enclose tidal marshlands and mudflats as a measure of land reclamation. Such device does not encourage scouring by the storm waves which are deflected by sea walls and their effects are reduced by intertidal areas with the result there is continuous accretion of mud on the seaward side of sea walls. Examples of such measures may be cited from the shore lines of Netherlands, Germany and Denmark.

(2) **Break Waters :** Efforts are made to shelter the harbours and the estuaries of river mouths being used as harbour from strong wave action and drifting of sand and shingle into the harbours through the construction of breakwaters which are extended from the coast towards the sea.

Generally five types of break waters are used as follows (fig. 15.3) :

(i) parallel break waters,

(ii) perpendicular break waters,

(iii) slanting break waters,

(iv) curved break waters, and

(v) enclosing break waters.

This human action results in the accumulation of sand and shingle and formation of beaches on the updrift side of breakwaters whereas beach depletion occurs on the downdrift side of **breakwaters** because of marked reduction of transport of sediments downdrift. The modification of coastal processes mainly of longshore drift transporting sediments at Newhaven harbour located on the mouth of Sussex Ouse river (southern coast of England) is a typical example of man's manipulation of coastal processes and positive and negative results arising therefrom. Breakwaters have been built to prevent the drifting of sands and shingles transported by the south-westerly waves into the entrance of the harbour. The result is that the river mouth, which was previously very often deflected by strong waves (before 1731), has been stabilised, shingle has accumulated on the western side of the breakwater (updrift side of the break-water), beach on the eastern side of the river mouth at Seaford has been depleted and cliff erosion at Seaford Head has been accelerated. This after-effect of protective measures of Newhaven harbour demanded protection of coastline and beaches from accelerated cliff erosion (induced by human activities) on long stretches of coastline east of the Sussex Ouse estuary.

Consequently, additional masonry and concrete **sea walls** have to be built along the vulnerable coast and groynes have to be inserted at right angle to the coast line. Other examples of updrift

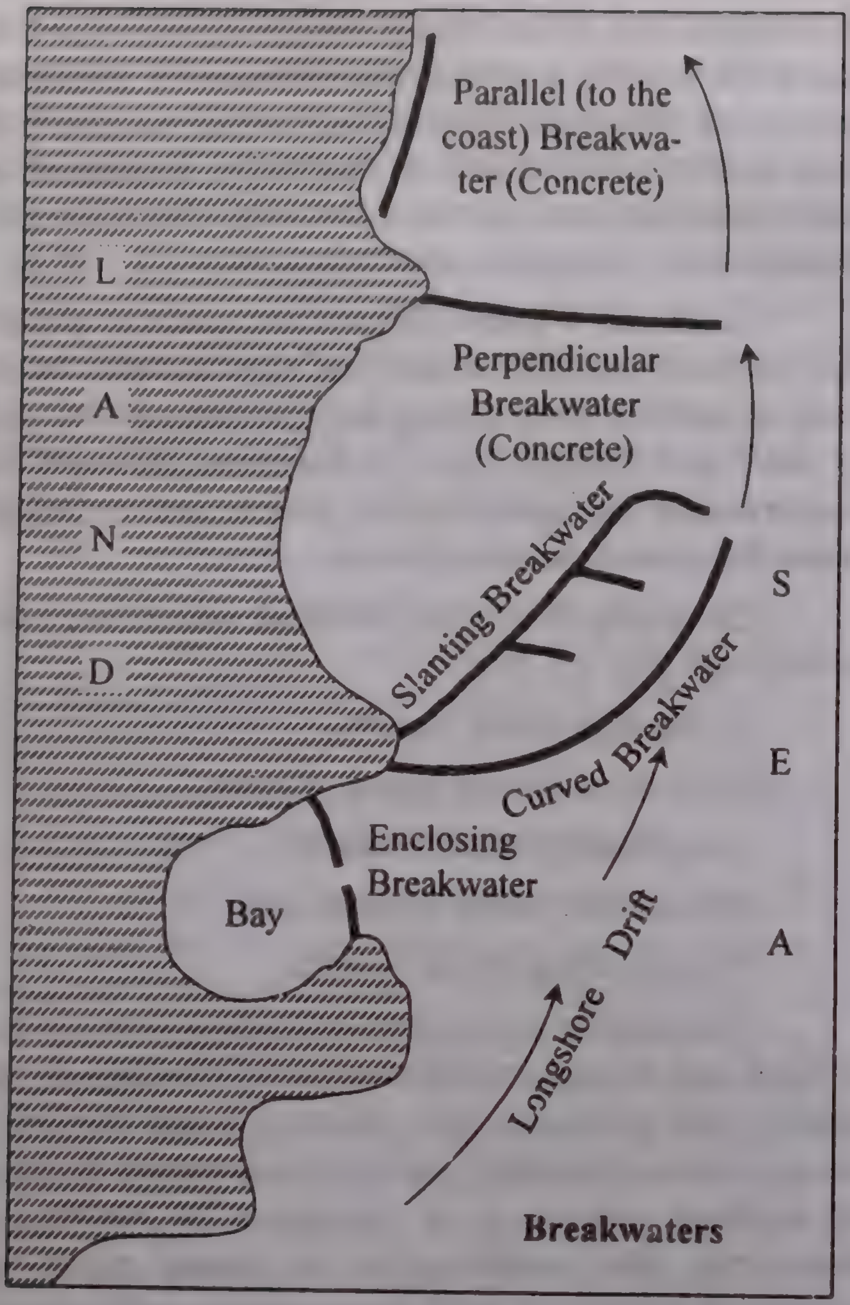

Parallel (to the coast) Breakwater (Concrete)
L
A
N
D
Perpendicular Breakwater (Concrete)
Slanting Breakwater
Curved Breakwater
Enclosing Breakwater
Bay
Longshore Drift
S
E
A
Breakwaters

Fig. 15.3 : Examples of different types of break waters.

accumulation of sediments and downdrift erosion of cliffs and beaches due to construction of breakwater include South Lake Worth Inlet (Florida coast, U.S.A.), harbour in Lagos (Nigerian coast), Durban Harbour (south African coast), Madras harbour (India, drifting of sand by northward longshore drift has been prevented and sand has accumulated to the south of harbour-breakwaters whereas beach has been eroded to the north of break waters), Santa Barbara (Californian coast, U.S.A.), Tweed River mouth on the east coast of Australia, Salina Cruz (Mexican coast) etc. In order to offset the depletion of beaches on down driff side due to breakwaters sand has to be pumped out from accumulated sand on updrift side of breakwaters under the harbour entrance so that the eroding beaches may be replenished. Some times offshore breakwaters are also constructed (e.g. Santa Monica, California, U.S.A.) to modify the waves reaching the coast.

Third type of break waters is enclosing one (fig. 15.3) to convert a bay into a harbour. This device changes the pattern of waves in terms of their energy and angle at which they strike the coast. The waves are refracted by enclosing breakwaters and these refracted waves erode the beaches with increased energy. Creation of Portland harbour on the south-eastern coast of Australia by enclosing the bay through the construction of breakwaters has resulted into severe beach erosion at Dutton Way located to the north of the harbour.

(3) **Groins :** In order to stop beach scouring and its depletion a series of groynes (these may be of huge rock masses, or of concrete or of wooden logs, fig. 15.4) are placed at close intervals at right angles to the seawalls or shore lines to reduce the loss of sand and shingle. In such cases the destruction of those parts of beaches which have closely spaced groynes may be retarded but the waves are deflected by these groynes and thus resort to scouring in those parts of the beaches where groynes are not inserted. The examples of depletion of beaches through human actions to stabilise the eroding cliffs through the construction of sea walls may be cited from

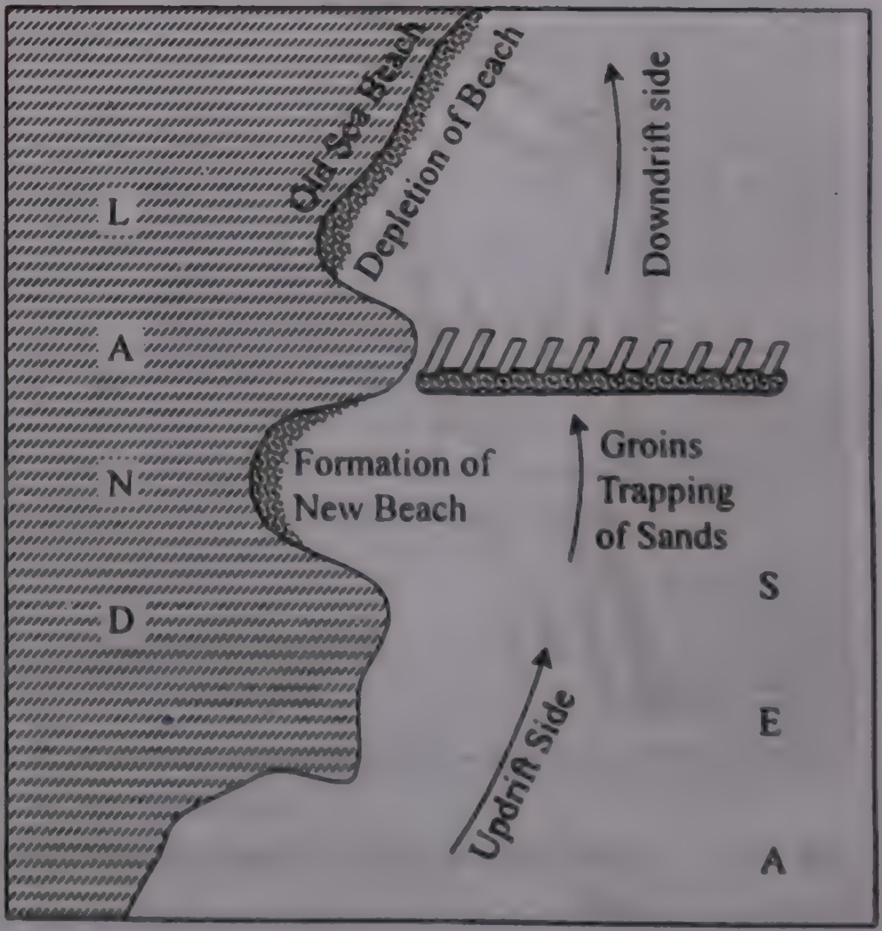

Old Sea Beach
Depletion of Beach
Downdrift side
L
A
N
D
Formation of New Beach
Groins Trapping of Sands
Updrift Side
S
E
A

Fig. 15. 4: Construction of groins perpendicular to sea coast.

Bournemouth (south coast of England), north-eastern shores of Port Phillip Bay (Australia) and many more.

Such groins have been constructed at Madras (Chennia) harbours to check sedimentation in the harbour.

Dredging

Dredging of ports and harbours to improve navigation channels modifies the pattern and velocity of waves and currents. The materials derived from dredging are generally dupmped at many alternative locations e.g. offshore locations, shallow areas adjacent to the harbour, onshore shallow areas (to reclaim land), beaches (to enrich them) etc. These dumped materials are reworked and dispersed by waves in a variety of ways. The dumping of dredged materials offshore creates new mounds which modify the direction, strength, velocity and overall pattern of sea waves. Some times sea floor is dredged to obtain materials to reclaim marshy coastal lands or to replenish eroding beaches. This activity deepens the sea floor which in turn generates long waves which erode the coastal land at relatively faster rate than the normal waves.

Govt. of India launched a massive project of **'Sethusamudram'** in July, 2005 for dredging the shallow portions of sea to the south of Tamil Nadu coast in order to connect the Bay of Bengal and the Gulf of Manar through Palk Strait inorder to facilitate easy and smooth movement of commercial ships between east and west coasts of the country. Thus circum-navigation of Sri Lanka would be avoided. The project was launched after proper analysis of environmental conditions of the area such as marine, land and socio-economic environment and proper environmental impact assement. The project also ensures to protect marine ecological resources mainly coral reefs in the Gulf of Manar and Palk Bay.

Sedimentological Characteristics

Man's activities also affect sedimentological characteristics of coastal environment as follows :

- There is additional supply of waste materials coming out of quarrying in the coastal zones. These materials are reworked and dispersed by sea waves and thus these materials are deposited in certain localities and new beaches are formed (example-progradation of beach ridge plain on the east coast of Jutland, Denmark, due to dumping of waste materials coming out from chalk quarry).
- Artificial replenishment of eroded beaches due to alteration of sediment supply caused by construction of breakwaters.
- Quarrying of beaches to obtain building materials leads to erosion of coastal land because of depletion of beach and direct exposure of coast to severe wave attack (example, quarrying of beaches for sand and gravel on Black Sea Coast of the former USSR resulted into severe wave erosion of Sochi coast which prompted to reverse the procedure by dumping of sand gravel to restore the beach and save the coast from continuous wave erosion). The other examples of beach nourishment through accumulation of sands and gravels by man include the beaches at Atlantic city (New Jersey, U.S.A.), Palm Beach (Florida, U.S.A.), West Haven (Connecticut, USA), Virginia Beach (south of Cape Henry, USA), Harrison county (Mississippi, U.S.A.), Californian coast (U.S.A.), Mentone (Shores of Port Philip Bay, Australia) etc.
- Devegetation and extensive cultivation, in the immediate hinterlands of the catchments of those rivers which drain the coast, result in progradation of coastal lands, phenomenal growth in beaches and deltas because of increased supply of fluvial materials brought by the rivers. This process has resulted into rapid rate of siltation of bays and inlets at the mouth of rivers along the Mediterraean coast due to extensive removal of vegetation (for increasing the cropland) and resultant accelerated rate of soil erosion and supply of enormous quantity of sediments.
- Construction of dams and reservoirs on major rivers (which drain into the seas) reverses the process of growth of beaches and deltas because the dams trap the sediments and force them to settle down in the reservoirs and therefore supply of fluvial sediments through the river mouths is markedly reduced. This results in rapid rate of erosion of beaches and deltas which causes retrogradation. It has been reported that the Nile delta is suffering

severe wave erosion and the shore line is receding at the rate of 40 m per year since the completion of Aswan High Dam in 1970.

- Marked removal of vegetation from stabilised coastal dunes through intentional clearance for economic use of the land, burning, grazing etc. accelerate wind erosion of coastal dunes and the eroded fine materials blown by the onshore wind are heaped inland. This process destabilises the previously stabilised coastal dunes (example, south-eastern Australian coast).
- Conversely, destabilised coastal dunes can be stabilised by planting trees, shrubs and grasses (example, Landes region, S.W. France, Culbin area on Scottish coast etc.).
- Reclamation of tidal marshes and mudflats through expanding earth fills from urban and industrial seaboard areas provides additional space for industrial installations, construction of buildings, roads and airfields on the one hand and poses problems of weak foundations of buildings, highways and air strips and destroys estuarine environment resulting into loss of marine food resources on the other hand.

15.6 MAN AND RIVER PROCESS

River is the most significant fluvial geomorphic process which shapes the surface of the earth at global scale. The erosional and depositional works of the rivers produce a variety of landforms on the earth's surface on the one hand and they (rivers) undergo their own transformation through the processes of river piracy, lengthening of channels through meandering, shortening of channels through the intersection of meander necks, braiding of channels due to aggradation and related branching of channels, drainage integration, changes in courses, changes of channel geometry and channel dynamics etc. under natural conditions without any anthropogenic manipulation on the other hand. Under natural conditions rivers are beneficial as well as disastrous for human society. The negative effects of rivers under natural conditions without being interfered by man include recurrent floods, changes in their coures, riparian erosion etc. which adversely affect human society (e.g. agriculture, transport network, settlements etc.). If the Nile became gift to Egypt and the Ganga became economic back bone of north India on the one hand, the Hawang Ho (now Yellow river) river became sorrow for China, Tennessee became hell for S.E.U.S.A., Damodar became menace for West Bengal (India)) on the other hand. Man, equipped with technological skil! has attempted to metamorphose river channels in two ways :

(1) to train the rivers to get rid off their disastrous roles, and

(2) to develop the rivers as natural resource for development purposes.

Channel Modification

The modifications of river channel processes by man may be grouped into two categories viz.

(1) direct or intentional modifications for useful purposes, and

(2) indirect or unintentional modifications which cause adverse effects on human society.

(1) Direct Channel Modifications

Direct modifications of channel processes include flood control measures, channel improvements, dams and reservoir construction, stream channelization (straightening, widening, and deepening of channels), bank manipulation through channel control structures (revetment-blanket revetment of rocks, concrete or other materials; pervious revetment of open fence and bskets; solid fence and groynes of solid structures at right angles to channel flow, training structures-timber pile dikes, rock dikes, rock-filled pile dikes, artificial earthen levees; closure of secondary channels etc.), and irrigation diversions (canals).

Direct channel modifications fall in two broad categories as follows :

(i) direct point modifications, and

(ii) direct reach modifications

(i) **Point modifications** : of channels at specific points or locations of the river concerned, called as 'point modifications', include the construction of dams and reservoirs for the purpose of water supply for domestic use, for supply of water for irrigating the crops through canals, for the generation of hydroelectricity; pumping of water for local water supply for domestic use and for lift irrigation canals;

disposal of used water from urban and industrial areas into the rivers at specific outfall points; construction of road and rail bridges across the rivers etc. The construction of dams on major rivers of the world has multiplied many folds since the start of the 20th century and thus more than 13 per cent of the total runoff of the world has been regulated by reservoirs. The storage reservoirs constructed behind the dams trap sediments and thus discharge pattern and sediment load of the rivers downstream are markedly modified. The study of effects of small structures on peak flow conducted by C.M. Moore (1969) has shown that peak discharge downstream from the reservoir may be reduced by 98 per cent to 50 per cent depending upon the level of water in the reservoirs. The trapping and settling down of bed load and suspended sediments in the reservoirs result in marked reduction in the sediment load of the channel downstream and this process encourages downstream erosion of river valley.

Withdrawal of water from rivers and pouring of water through pumping into canals (lift canals) in India during post-monsoon period of lean discharge of rivers causes siltation of river beds and reduces water retaining capacity of the valley resulting into increase in the dimension of floods. Construction of bridges modifies the direction of channel flow and increases flow velocity which encourages downstream erosion. The construction of a road bridge 500 m downstream from the old railbridge on the Gomti river near Kaithi village (Varanasi district, India) straightened the course of the Gomti river which resulted into the shifting of the confluence of the said river with the Ganga river in 1980 by 2 km upstream from the old confluence because of accelerated erosion through meander loop which was hardly one km away from the Ganga bank (Savindra Singh, 1983).

(ii) **Reach modifications :** involve a sizeable span of the channel. The highly sinous channels are straightened by cutting off meander loops so that the channel reach may be shorterned in length and the velocity of water is increased to allow quick disposal of water during floods downstream through increased frequency of peak discharge. The lower Mississippi river near Greenville (Mississippi, USA) was shortened in its length from 530 km to 185km between 1933 and 1936 to reduce flood crests. Similarly, the Missouri river was shortened in its length by 52 km between Sioux city and its confluence with the Mississippi in 1960 for flood control and navigation improvement. It may be pointed out that meandering is a natural process of alluvial rivers and it is very difficult to prevent the rivers from developing meander bends by artificial cutoffs of individual natural bends. If old meanders are cut off and the channel is straightened, the river develops new meanders. The dredging of channels either for navigation purposes or for obtaining sands and gravels as building materials increases the amount of sediment for transport downstream. The regulation of river to halt riparian (bank) erosion decreases the supply of sediment downstream which results in downstream scouring.

The other devices to regulate river channels include the construction of a series of large flood-control or flood-storage reservoirs on a particular river, widening and deepening of channels for preventing seasonal overbank flooding, construction of dykes, embankments etc. on river banks to protect the cities and towns from overbank flooding, provision of flood-diversion system etc.

(2) **Indirect channel modifications :** Indirect modifications of channel processes include the changes of general surface characteristics of the entire catchment area or part thereof through deforestation. The bare ground surface cuused due to deforestation is eroded at faster rate on the one hand and generates more surface runoff on the other hand. This process increases both stream discharge and sediment load which changes the channel regime in terms of river metamorphosis which includes changes of channel geometry, channel planform and sediment transport.

The Yellow river of China transports the highest amount of average annual silt load of 1640 million tonnes from intensively cultivated upland surfaces of wind deposited loess in Shensi and Shansi provinces whereas the Ganga river carries the second highest amount of sediment load of 1450 million tonnes per year derived from the deforested steep mountain slopes of the Himalayas and from intensively cultivated alluvial plains. Conversely, the Mississippi river occupying roughtly three times more catchment (3,269,000 km^2) than the Ganga catchment (9,55,000 km^2) carries much smaller amount of sediment load (850 million tonnes/year). 'Thus the high rate of sediment load of the Ganga reflects the deforestation of the source areas of the Ganga system (the Himalayas and the foreland of Indian Peninsula) which has accelerated the rate of erosion of surficial materials' (Savindra Singh and Alok Dubey, 1989)

Human activities responsible for the aggradation and siltation of river valleys due to increased sediment supply include accelerated soil erosion consequent upon extensive and itensive cultivation, deforestation, natural and deliberate forest fires, mining operations, urbanisation and highway construction etc., all of which not only increase sediment supply to cause channel aggradation but also increase suspended load of the channels which travels downstream and is deposited in lakes, reservoirs and estuaries and thus adversely affects the aquatic life.

15.7 MAN AND PERIGLACIAL PROCESSES

Periglacial areas are those which are in permanently frozen condition but there is no permanent ice cover on the ground surface. The mean annual temperature ranges between -15°C and 1°C and mean annual precipitation is between 120 mm and 1400 mm (mainly in solid form). The most striking feature of periglacial areas is the **'permafrost'** (permanently frozen ground) and the **'active layer'** which is the uppermost layer of the periglacial area. The 'active layer' is characterised by diurnal freeze (during night) and thaw (during day time) cycle during the intervening periods of summer and winter seasons. It is completely frozen during witner and is thawed during late summer. The depth of 'active layer' ranges from a few centimetres to 3 metres. All the periglacial processes viz. congelifraction or frost weathering, congelifluction or solifluction, frost heave, nivation and of course fluvial processes (during summer) operate in the **'active layer'** and the main driving force of the periglacial processes is related to thermal conditions. 'Permafrost' lying below the active layer represents the permanently frozen ground upto varying depths. About one fifth of the surface area of the globe is covered by permafrost (including both continuous and discontinuous types). The largest areas of permafrost are in Siberian part of Russia, Alaska (USA) and northern Canada.

The understanding of nature, behaviour and characteristics of permafrost and mechanism of periglacial processes is of paramount significance for man if any development programme related to cultivation, settlement, highways, mining etc. is to be extended to permafrost areas because it poses greatest problems of construction and engineering works of all the other environmental processes. In fact, all aspects of human activities in the periglacial areas are affected by permafrost and periglacial processes. All of the constructions made by man for the colonisation of the tundra region of North America (roads, railways, bridges, buildings, factories etc.) before the knowledge of deceptive nature of permafrost have been greatly deformed. The laying out of rails for Trans-Siberian rail line in Siberia also suffered great damages in the initial stages because of thawing of permafrost due to vegetation removal and consequent subsidence of ground surface. Now greater attention is paid towards the study of permafrost in Canada, USA and Russia. The PISAS (Permafrost Institute of the Siberian Academy of Sciences at Yakutsk) of Russia and CARREL (Cold Region Research and Engineering Laboratories, at Hanover, New Hamphire) of the USA are actively engaged in the study of permafrost and periglacial processes.

Two specific periglacial processes need special mention because these affect human activities most. These are thermokarst and frost heave. Thermokarst is both process and landform. Thermokarst refers to collapse, sinking and subsidence of ground surface caused by disturbance in the thermal equilibrium of permaforst (due to increase in temperature). The process is most active in the areas of unconsolidated frozen materials. The effect of thermokarst in consolidated frozen parent rock is negligible. Frost heave refers to bulging of ground surface due to ice seggregation. Thus if thermokarst causes subsidence of ground surface due to thawing of frozen moisture and creates several sinks and cauldron subsidence of varying dimensions, frost heave renders the ground surface uneven.

There are several natural and anthropogenic factors which upset thermal equilibrium of permafrost which in turn either causes thawing of frozen ground moisture and induces thermokarst or encourages ice seggregation to foster frost heaving. The degradation of permafrost through thermokarst or frost heaving largely depends on the following :

- the nature of geomaterials, whether unconsolidated or consolidated,
- content of ice present in the permafrost, nature and density of vegetation on the ground surface,
- insulating properties of surface vegetation, and
- duration of sunlight and quantity of insolation during summer days. The activities of man destabilise thermal conditions of permafrosts and render them hazardous for human society in the following manner :

(1) Removal of surface vegetation either through direct felling of trees or constructional purposes allows sun's rays to reach the ground surface directly and thus ground temperature is increased. It may be pointed out that surface vegetation acts as insulator to solar rays and protects the ground surface from direct solar rays. Temperature thus increased due to removal of surface vegetation causes thawing of ice in the permafrost which causes subsidence of ground surface and changes the ground surface into undulating surface dotted with tiny mounds and small depressions. Such changes of ground surface have been recorded in Fairbanks region of Alaska where extensive clearance of surface vegetation for cultivation in the decade 1920-30 led to formation of undulating surface characterised by numerous mounds of 3 to 15 m diameter and of 2.4 m height. The increase of temperature by 14°C upto the depth of 40 cm has been reported from Yenesei region of Siberia. This increase of temperature has been related to deforestation and cultivation.

(2) Excavation activities of obtaining materials for construction (e.g. for the construction of roads, airstrips of air ports) or for laying down water pipes lines, etc. disturb the thermal equilibrium of permafrost and cause the ice lenses to melt which allows the ground surface to subside.

(3) Regular driving of vehicles over the thawed permafrost surface during summer season destroys surface vegetation and causes trenching in the soft and wet ground surface. Such trenchings, if caused on slopy ground, develop into gullies because these trenches channelise the snow-melt and surface runoff.

(4) Forest fire, either natural or deliberate, in permafrost regions changes the ground thermal regime through vegetation destruction. Increased temperature due to fire and consequent removal of vegetation deepens the thickness of active layer and thus the thermokasrst process starts. Increase in the depth of active layer by 45cm has been reported from Siberian Taiga of Russia due to forest fire in 1953.

It may be pointed out that terrian disturbance caused by man through excavation pits (for extraction of construction materials from the ground), movement of vehicles, road-cuts etc. thins out the 'active layer' whereas deforestation, cultivation, construction of roads, rails, buildings and drainage changes thicken the 'active layer'. In either case the thermal equilibrium of permafrost is disturbed which induces thawing of frozen moisture of permafrost, release of excess ice and ultimately ground surface undergoes the process of subsicnece.

Degradation of permafrost in the periglacial areas either caused by human activities or natural processes poses severe problems of engineering works and hydrological regime. Suitable geotechnical meaasures and advanced engineering devices are needed for any successful constructional works to be extended in the more remote northern regions of permafrost in Alaska (USA), Canada and Siberia but these devices are so costly and complicated that the net results are limited but the fragile permafrost environments are more rapidly degraded.

15.8 MAN AND SUBSURFACE PROCESSES

Subsurface environment is largely affected by human activities and the consequences are rather more hazardous and disastrous to human society than any other modification of environmental processes by man. The impacts of human activities on subsurface conditions are increasing day by day with everincreasing population. The changes of subsurface environment mostly include changes in subsurface materials e.g. expansion or contraction, loosening or compaction, fracturing and displacement, upward or downward movement, decrease or increase of stresses, deformation of subsurface materials etc. The impacts of these changes are so deceptive and slowly cumulative that these are not realised and detected before real damages are done. The after-effects of these changes are so complicated and are so polygenetic that it is very difficult to predict them well in advance. Since these changes are confined to underground environment and their causes are so complicated that their prevention and control are very difficult.

Man changes subsurface conditions in a number of ways such as :

(1) introduction of additional artificial superincumbent load through :
  (i) construction of big dams, and
  (ii) impounding of huge volume of water in big reservoirs.

(2) injection of used and waste water through injection wells into the ground.

(3) supply of water through irrigation in the agricultural farms.

(4) withdrawal of water and mineral oil from the ground.
(5) underground mining.

(1) Introduction of Additional Artificial Loads

Man changes subsurface conditions by putting additional load on ground surface through the construction of dams and reservoirs, highways and bridges, canals, injection of water underground, buildings, irrigation etc. and by reducing load and pressure underground through water withdrawal, drilling of mineral oil and natural gas, underground mining, mining of solid materials etc. It may be pointed out that any change in subsurface environment occurs only when the impact of human activities exceeds the resisting force of the geomaterials.

The introduction of additional artificial superincumbent load through the construction of big dams and impounding of huge volume of water in big reservoirs causes disequilibrium of already isostatically adjusted rocks below the reservoirs or further augments the already fragile structure due to faults and fractures underneath. This process causes earthquakes of varying intensity which inflict damage to human life and property. Many major seismic events have been correlated with dams and reservoirs all over the world (e.g. earthquake of 1931 in Greece due to Marathon Dam constructed in 1929, start of earth tremors since 1936 around Hoover Dam (USA) due to creation of Mead Lake in 1935; Koyna earthquake of 1967 (India) due to Koyna reservoir constructed in 1962; other examples of significant earthquakes caused by dams and reservoirs are of Monteynard and Grandvale in France, Mangla in Pakistan, Kariba in Zambia. Manic in Canada, Hendrick Verwoerd in South Africa, Nourek in former USSR, Kurobe in Japan, Hsinfengkiang in China etc. Underground disturbance due to hydrostatic pressure of water in the reservoirs also causes landslides and earthflow along the natural and artificial walls of the resrvoirs. It may be pointed out that the intensity of earthquakes has been positively correlated with the levels of water in the reservoirs.

(2) Use of Injection Wells

Subsurface equilibrium is also disturbed at some places due to pumping of used and waste water through injection wells into the ground. At some places water is injected into aquifers to remove either salt water intrusion or to check contamination of groundwater through inflow of saline water in coastal areas. Another way of injecting water underground is to pump water into mineral oil strata to increase hydrostatic pressure so that oil may be pushed upward and production of oil may be augmented. In all such cases subsurface equilibrium is disturbed and seismic activities are set in.

(3) Irrigatin of Agricultural Fields

Yet another way of increasing superincumbent load of ground surface is the supply of water through irrigation in the agricultural farms. When irrigation waters are spread over loose and dry soils in the arid and semi-arid regions, the loose and dry materials are wetted and compacted under the process of hydrocompaction. The result of such hydrocompaction is subsidence of general surface upto 1-2 metres, which causes damage to irrigation drains, canals, casings of wells, roads, water and oil pipe lines, buildings etc. The overload exerted by buildings in the areas of recent infilled materials causes land subsidence and resultant great damages to buildings, road and pipe lines. Ill-designed construction of houses in the permafrost areas causes thawing of frozen moisture which encourages subsidence of land surface and buildings.

(4) Mining of Groundwater and Petroleum

Certain human activities reduce the load of subsurface environment by withdrawing fluids (water and petroleum) and solid materials (minerals and rocks). Extraction of groundwater through pumpsets and tubewells at a much faster rate than the recharge of groundwater through annual infiltration of precipitation results in lowering of water table which causes depletion of groundwater resources on the one hand and the empty cavity consequent upon 'groundwater mining' and lowering of water table allow the ground surface to collapse on the other hand. The examples of subsidence of ground surface due to extraction of groundwater have been already quoted in chapter 3 on 'Man-Environment Relationship'. It may be pointed out that subsidence of ground surface due to 'groundwater mining' mostly occurs in those areas where the subsurface materials are loose and unconsolidated. The extraction of mineral oil and natural gas from consolidated lithologies causes cracks, fractures, faults and subsidence at local scale.

(5) Mining Activities

The mining of solid materials like coal, gold, copper, limestones etc. through underground mining causes collapse of overlying surface.

Some times the underground mining reaches the water table and water finds its way into the mine, so water is pumped out to extend the mining further underground. If such situation is associated with limestone or dolomite lithologies, man-induced sink holes develop on the ground surface which allows the surface water to disappear through these sink holes and causes surface collapse and depletion of surface water resources. Dewatering of underground mines also result in drying out of springs due to lowering of water table. The example of dewatering of gold mines in the Far West Rand Mining District Near Johannesburg (Union of South Africa) tells the impact of dewatering of deep mines on ground surface and ultimately on human society. A score of sink holes were developed in the said areas (1962-1966). The largest sink hole was 125m in diameter and 50 m in depth. Some times deep coal mines are left over without filling them and new mines are started near the old ones. In such cases the old unfilled mines are filled with rain water and there is instrusion of water through the intervening walls into the active mines. The process, sometimes, is so sudden that all the workers are submerged and drowned in the active mines. Chasnala tragedy (Jharkhand, India) very well illustrates the folly of human activity as water from the old left-over Chasnala coal mine gushed into the adjacent active mine and all the workers in the mine lost their lives.

Underground mining also leads to diversion of underground flow, disruption of water flow regimes, release of harmful gases, rockbursts, outbursts of geomaterials, subsidence cracks on the ground surface, ground surface disruptions etc. Localised but more powerful human activities such as use of dynamites to blast rocks for highway construction, clearance for dam sites and of course the most powerful but disastrous nuclear explosions cause surface deforamation and more powerful earthquakes. Surface transoframation in periglacial areas brings harzardous effects for huamn society (see previous sub-section).

15.9 MAN AND PEDOLOGICAL PROCESSES

Soil is very important natural resource because it provides all sorts of food to man as well as it provides bases of life to terrestrial and aquatic flora and fauna in one way or the other. The physical processes operating in different soil horizons of a difinite soil profile (see chapter 7) determine the general properties of soils. Soil largely influences human activities which in turn also affect labile soil characteristics (those characteristics which are susceptible to external changes occasioned by man). Thus the study of interrelationships between soils profile processes and human activities is of paramount significance for better land use management. The formation of soil is a very slow natural process as the development of one inch thick soil requires one thousand years but man can degrade, destroy and change the soils within very short period through his various economic activities. The use of soils is must because these are fundamental to the survival of human beings but the mechanisms of varous soil profile processes and their responses to external changes brought by man must not only be realised but must be also studied properly so that a particular soil is utilised in right manner.

The apparent **direct impact** of man on total soil is total loss of all horizons of soil profile due to accelerated erosion consequent upon removal of surface vegetation mainly of slopy ground. The **indirect human impacts** include changes of soil properties of different soil horizons of soil profiles through various economic activities. It is, therefore, necessary at the very outset to study the characteristics of different horizons of soil profiles of different kinds of soils in various climatic and vegetation zones. At the second level, there should be micro-level study of various responses of soil components and soil profile processes to inputs applied by man to the soils and various responses of farm techniques and land use practices to soil profile processes. At the third level, there should be comprehensive planning for better soil conservation and management. The last theme will be discussed in section 16.2 of chapter 16 (conservation measures of soil erosion). Soil pollution will be discussed in chapter 21.

A record of past history of interactions of man with soils may be very helpful in understanding the ways the soil characteristics have changed overtime.

Similarly, the historical study of soil profile evolution enables us to ascertain (i) the process of development of man-induced properties in the present soils, and (ii) the rate of operation of various soil forming processes helps to predict the changes in soil forming processes in future. It may be pointed out that ploughing of soil for agricultural purposes acts as a process of redistribution and homogenisation of constituent elements of soils in different soil horizons of soil profile. S. Trudgill (1981, p. 194) has reported that unploughed chalk soils contain high humus content of 8-14 percent organic carbon in 'A' horizon of dark brown colour whereas ploughed chalk soils contain low humus content of only 2-3 per cent of organic carbon because the humus content is distributed in all the horizons of soil profile due to ploughing. Conversely, calcium carbonate content in unploughed chalk soils in natural condition may be as low as 15-20 per cent but it may increase to 68-80 per cent after ploughing because ploughing helps in bringing the chalk to the upper horizons from the sobsoil (S. Trudgill, 1981).

S. Trudgill has spelt out two procedures to estimate the rate of soil profile formation viz. (i) dating of buried soil horizons with the help of pollen analysis on the basis of pollen preserved in the soils and C-14 dating, and (ii) deductions of the rate of soil development from historical evidences from a known starting point (by enclosing uncultivated land). Two specific studies in two different localities of U.K. reveal the rate of soil development in terms of changes in minerals and organic matter. The studies of soil organic profiels by K. Crabtree and E.M. Maltby (1975 and 1976) on Exmoor land (U.K.) from 1833 to 1974 have revealed marked increse in organic matter from 20 grams per m^2 per year while the study of soils of Romney Marsh reclaimed from sea at various times (started in the 9th century) by R.D. Green (1968) has indentified decalcification as the main process of soil development. The results of these studies denote that the organic matter in the soil changes at much faster rate than certain minerals in response to changes in external conditions introduced by human activites.

Agricultural practices and farm techniques are supposed to affect soil profile processes and soil properties. The introduction of modern technology involving heavy and huge farm machines results in the alteration of soil structure in certain conditions (wet silt soils) through compaction. Overgrazing of pasture with big animals (cow herds, pigs etc.) deteriorates the structure of wet soils. Increase in the amount of organic matter responds positively to the stability of soil aggregates. The content of organic matter in the soils is very important on two counts viz. (i) organic matter absorbs the soil pollutants added by man to the soil and thus renders soil pollutants less harmful, and (ii) organic matter present in the soils allows growth of organisms living in the soils which may decompose certain cartegories of soil pollutants. The significant soil pollutants added by man are pesticides (to kill insects harmful to crops) and herbicides(to destroy the wild growth of undesirable plants in the crop fields). The pesticides and heribicides used by man fall into two categoreis e.g. (i) those which are decomposed by soil organisms and thus are absorbed in the soil profiles, and (ii) those which are not decomposed but remain persistent with high concentration. The last category of pesticides and heribicides is harmful to soils as these pollutants alter the soil chemistry. The decomposed heribicides and pesticides partly reach the food chains and are partly drained to water bodies like rivers and lakes by hydrological processes.

Besides pesticides and heribicides, there are pollutants of heavy metals like zinc, copper, lead, mercury, cadmium, chromium etc. which are added to soil profile from natural (geological formations) and man-made sources (ore mining and direct application of certain minerals to the field crops like zinc). These solid matters are seldom decomposed by soil organisms and are relatively insoluble in the soils. Consequently, they do not reach water bodies in solution but their persistence and concentration in the soil profiles change the soil properties by contaminating them.

The presence or absence of acidic and alkaliine elements in the soil profiles affects decomposition of solid substances added by man to the soils. Heavy metals are generally decomposed by acid contents of soils and thus these dissolved solid materials are changed in solution form and are partly consumed by plants through root osmosis and reach the food chains and are partly removed by hydrological processes and find their way to water bodies like streams and lakes whereas alkaline soil profiles are not capable of dissolving solid metals. The sulphur contents reaching the soil profiles through fallout of aerosol emitted by factories acidify the soils and thus help in decomposing solid metals. It may be pointed out that minimum amount of certain elements like copper, zinc, sulphur etc. is necessary for plant growth and so long as the amount of these elements is within permissible threshold values these seldom become pollutants but increased amount may become injurious to soil profiles and consequently to plant growth but the presence of nickel, lead, mercury, chromium, cadmium etc. is not desirable as these elements are, without doubt, pollutants and degrade soil profiles.

The use of chemical fertilizers to enrich soils for incresed food production is rapidly increasing in response to increasing food demand to feed the teeming millions. Economically and socially the use of chemical fertilizers is desirable but these should be used with proper care based on understanding of soil properties and their ability to assimilate these fertilizers. For example, nitrates are very important for plant growth but since nitrogen is soluble and is easily leached downward, the amount to be applied to the soils should be decided in accordance with the structure of soils. Excess use of nitrogen in loose, coarse grained and well drained soils like sandy soils, results in greater loss of nitrogen because it being quickly dissolved moves away with water movement. Conversely, phosphates are absorbed in the soils and are concentrated in the soils and may not be available to plants. Acidic soils with iron, aluminium or managanese contents encourage the fixing of phosphates whereas alkaline soils discourage solution of calcium phosphate. All these result in the concentration of phosphate in the upper horizon of soil profile but this concentration seldom adversely affects the productivity of soils but the leaching of nitrates and their movement to streams and lakes encourages unwanted plant growth which adversely affects the aquatic organisms.

Changes in plant cover in terms of changes of plant species also alter the chemical properties of soils profiles. It may be pointed out that the adverse effects of human activities on soil profile processes and soil characteristics do not necessarily mean to undermine the value of soils as fundamental resource to huamn society. What is desirable to make soil resources more useful to human society is to understnad the processes of soil formation (see chapter 7 on **soil system**), the mechanism of operation of soil forming processes, the mechanism of operation of soil profile processes, the properties of soils, the nature and rate of various responses of soil characteristics and soil profile processes to external inputs added by man to the soils so that better soil management strategies may be evolved to get maximum benefits from soils without degradating them.

16

MAN-INDUCED SOIL EROSION AND SEDIMENTATION

16.1 FACETS OF SOIL EROSION

Various aspects of soil system viz. components, soil texture, soil strucutre, soil profile and horizon, formation of soils and classification of soils have been discussed in the 7th chapter while the impact of man's activities on pedogenic processes has been described in the 15th chapter. Soils, defined as loose and unconsolidated materials derived through the breaking down of rocks, are in fact very heart of the life layer known as the biosphere becasue these represent a zone wherein plant nutrients are produced, held, maintained and are made available to plants through their roots and to the micro-organisms which live in the soils. Soil is also very significant environmental attribute for human society because :

- It is the basic medium for food and timber,
- It provides foundations for buildings and roads, and
- It is very important exhaustible natural resource because it cannot be replacd if it is destroyed or lost through excessive soil erosion caused by anthropogenic activities and it is the base for the development of human civilization.

Erosion is a comprehensive natural process of detachment and removal of loosened rock materials and soils by exogenetic processes such as running water, groundwaer, sea waves, wind, glacier etc. Erosion caused by natural processes without being interfered by huamn activities is also called **geological erosion.** It may be pointed out that 'slow removal of soil is a part of the natural geological processes of denudation and is both inevitable and universal' (A.N. Strahler and A.H. Strahler, 1976). **Accelerated erosion** refers to the increased rate of erosion caused by various land use changes effected by man. Thus **soil erosion** normally means acelerated erosion which is also called as **man-induced soil erosion** because of greater impact of human activities than natural factors on soil erosion. 'Thus, soil erosion is an extreme form of soil degradation in which natural geomorphological processes are aecelerated so that soil is removed at rates ten and sometimes several thousand times faster than is the case under the conditons of natural vegetation, and much faster than rates at which new soil forms' (R.P.C. Morgan in K.S. Richards, R.R. Amett and S. Ellis, 1985).

In fact, the damage and degradation caused to the soils due to compaction, smearing, excessive working, pulverisation etc. through human activities is called **soil degradation** which is responsible for the removal of fertile upper soil horizons at the rate faster than they can be formed, decline in the organic content of the soil and several types of changes in the physical and chemical properties of the soils. Accelerated soil erosion or man-induced soil erosion is mostly operative in the humid climatic regions where extensive forest clearance (tropical and sub-tropical forest biomes), grassland removal (steppes and prairies) and extensive overgrazing and trampling by livestock have been practiced by man at an alarming rate.

Machanics and Forms of Soil Erosion

Soil erosion involves mainly two processes as follows :

(1) loosening and detachment of soil particles from the soil mass, and

(2) removal and transport of the detached soil particles downslope (if the soil erosion is being effected by raindrops and overland flow on the soils developed over hillslopes), downstream (when the soil is eroded by rills, guillies and channels) or down wind (in the case of soil erosion through deflation by wind or aeolian process).

Though the mechanisms of **man-induced soil erosion** are more or less similar in all those areas where human activities have largely modified and changed the land use patterns but some distinctions may be drawn between the mechanisms and rates of soil erosion on hillslope and ploughed flat plains.

L.D. Meyer and W.H. Wischmeier (1969) have identified two types of soil erosion due to the impact of raindrop on soil surface and the action of runoff on a hillslope having thin to thick veneer of soils as follows :

(i) transport-limited soil erosion, and

(ii) detachment-limited soil erosion.

If the detachment of soil particles and hence the soil erosion equals the rate of transporting capacity of the agents of transport e.g. rainfall and runoff, the soil erosion is called **transport-limited erosion,** on the other hand if the rate of detachment of soil mass is lower than the transport capacity of the transporting agents, the soil erosion is called **detachment-limited erosion.**

The degree of detachability of soil particles from soil mass is a crucial factor for soil erosion. The detachability largely depends on grain-size or the size and the cohesiveness of the particles. The detachment of particles having the grain size of above 0.2 mm requires more force provided by the velocity of moving water. In other words, the required critical velocity to detach soil particles increases with increase in the grain size above 0.20 mm. In such case the detachability is controlled by the size and weight of particles because more force in the form of velocity of moving water is required to dislodge larger and heavier particles. It is interesting to note that the required critical velocity to detach and dislodge particles from the soil mass also increases with decrease in grain size below the grain size of 0.20 mm because finer particles are heavily compacted and thus such cohesive materials also require greater force of velocity of moving water to be detached from their soil masses, but if the finer and smaller particles are not compacted, the critical force of the velocity of moving water may slightly decrease.

The raindrops strike against the open and bare ploughed ground surface with greater kinetic energy in the absence of any interception barrier of vegetation. This results in the breaking down of the soil aggregates into fine particles which are thrown up in the air by the impact of falling raindrops and resettle on the ground surface. This process of soil erosion is called **splash erosion.** The resettling of upthrown soil particles (caused by splash erosion as referred to above) on the top horizon of soil profiles results in the plugging and sealing of larger openings and the formation of strong impervious thin layer acting as cuirass which prevents infiltration of rainwater and thus generates surface runoff and overland flow. The overland flow picks up the soil particles and carry them. This sort of removal and transport of soil particles is called **entrainment.** When the soil is eroded in thin layers, the process is called **rainwash or sheet erosion.** When there is heavy rainfall associated with rainstorms, the overland flow or sheet flow is transformed into linear flow called as rill, and the soil erosion caused by rills is called **rill erosion,** or simply **rilling.**

As the process of rill erosion continues numerous interconnected rills are formed. These closely spaced dense networks of rills or narrow channels are called **shoestring rills.** These rills are very often destroyed every year by tillage if farming is practiced every year but when these are not destroyed by soil tillage, the rills are established into the soils and subsoils, are enlarged and deepened and are finally transformed into long and deeper channels which are called **gullies.** The rills are very frequently transformed into gullies over the slopy grounds and the foothill zones of the hillslope which have been divested of their vegetal cover either through mass-felling of trees or extensive overgrazing and trampling by livestock. The soil erosion caused by rills and gullies is called **rill and ravine erosion** which is the most powerful and effective form of soil erosion. The heavily gullied and ravinated land is called **badland.**

The erosion of soils through raindrops (splash erosion) and overland flow or surface wash (sheet erosion) of the areas situated between two rills is called interrill erosion whereas the rill erosion is caused by concentrated channel runoff. Similarly, the erosion of the soils of the ares situated between two gullies is called **intergully erison** whereas gully erosion is caused by concentrated and enlarged rills resulting from the integration of several rills. The interrill and intergully erosion is transport-limited where the rill and gully erosion is detachment-limited. The rills and gullies extend headward at varying rates depending on the characteristics of soils, nature of slope and amount and intensity of rainfall. The magnitude of soil erosion caused by rill and gully erosion or ravine erosion may be gauged from the fact that the gullies are extending at the rate of 4-5 m per year through headward erosion and 2.35 million cubic metres of agricultural land are lost every year from Jawa Block of Rewa District of Madhya Pradesh, India (Savindra Singh and S.P. Agnihotri, 1987).

16.2 FACTORS AND CAUSES OF SOIL EROSION

Different forms of soil erosion such as splash erosion, sheet erosion or rainwash, interril erosion, rill erosion, ravine and gully erosion are related to raindrops, runoff, overland flow and subsurface water under varying environmental conditions. M. Morisawa (1968) has identified two major independent facors which control the rate and type of soil erosion occuring on hillslope e.g. **climate** and **geology.** Intensity, amount and duration of rainfall are determined by climate and these in turn determine the nature and characteristics of natural vegetation of the region concerned. Vegetation, in turn, also affects different parameters of rainfall (e.g. intensity, amount and duration). Availability of sunlight (a factor of climate) is also an important factor which controls vegetation. The overall characteristics of soils of the region concerned are dependent upon two basic components of geology viz. rock type and topography and on climatic factors. Thus vegetation is dependent on climate and soil characteristics (both physical and chemical) are dependent on climate and regional geology (rock type and topography). **Vegetation** influences soils through :

- the actions of roots which bind the soil particles together,
- uptake of nutrients by plants through their roots under the process of root osmosis,
- release of organic matter to the soil horizons,
- interception of raindrops and thus protection to the soils from splash erosion, etc.

The effects of these factors (rainfall characteristics, vegetation and soil properties, which are highly interrelated among themselves) on soil erosion wil be discussed later in this subsection.

Soil Erosion Equation

The following equation expresses the meaning and basic factors of soil erosion :

$$SE = f\,(Eros, Erod) \qquad \ldots\ldots\ldots(16.1)$$

Where SE = Soil erosion
f = function of
Eros = Erosivity
Erod = Erodibility

In other words, erosion is a function of the **erosivity** of soil erosion processes (i.e. the eroding power of raindrops, running water and sliding or flowing earth masses) and the **erodibility** of the soils.

Erosivity is defined as the potential ability of processes (such as raindrop, running water in the form of runoff and overland flow and sliding or flowing earth masses) to cause erosion of soils in certain set of environmental conditions. The erosivity of processes depends, besides other environmental factors, on the nature of disposition of rainwater on the ground surface or in the soil profiles. For example, if the ground surface is covered with dense vegetation, the rainwater follows a very complicated route before reaching a nearby channel e.g. raindrop is intercepted by vegetation→intercepted water reaches the ground surface through the leaves, branches and stems of trees as **aerial streamlets**→this water slowly and slowly infiltrates into the soil→goes to the contributing area via **throughflow**→which ultimately reaches the nearest stream channels. Alternatively, if the ground surface is intensively cultivated agricultural field or unconvered bare ground fallow land the raindrops strike the bare ground, and generates maximum overland flow which reaches the nearest stream channel without being much infiltraed into the soils and ground surface.

Soil erodibility : refers to the resistance of the soil to erosion or its vulnerability to erosion. Soil erodibility is dependent upon soil characteristics such as its physical and chemical characteristics (particle size distribution, structure, organic matter content, permeability, root content, shear strength, aggregate ability, tendency to surface crusting) and the nature of treatment of soil under land use (such as cropping pattern, forestry, grazing etc.) and management (such as application of agricultural implements, irrigation and fertilizers, types of farming, cropping pattern, harvesting etc.).

The **factors,** which control soil erosion, include climate, topography, rock type, vegetation and soil characteristics. These factors operate together and are expressed as **universal soil loss equation** as follows :

$$E = f\,(C, T, R, V, S)\ldots\ldots\ldots\ldots(16.2)$$

Where E = Soil erosion
f = function of
C = Climate
T = Topography
R = Rock type
V = Vegetation
S = Soil character (physical and chemical properties)

The Food and Agriculture Organization (FAO) has listed (1965) the factors of soil erosion in slightly a different manner. According to FAO the following are the important factors which influence soil erosion :

(i) Physiographic factors : length, steepness and curvature of slope
(ii) Climatic factors : quantity, intensity, energy and distribution of rainfall and temperatrue changes
(iii) Soil characteristics : detachability and transportability, aggregation and surface sealing, depth, water-holding capacity
(iv) Cover or vegetation : cultivated, fallow, forests

These factors of soil erosion have been used to build a model of soil erosion which is known as **universal soil loss equation** as given below :

$$E = f\,(R, K, L, S, C, P, \ldots\ldots(16.3)$$

Where E = avaerage annual soil/sediment loss
f = function of
R = rainfall factor (quantity, intensity, energy and distribution of rainfall)
K = soil erodibility factor(chemical and physical characteristics of soils as referred to above)
L = length-of slope factor
S = Steepness-of slope factor
C = Cropping and management factor
P = conservation practice factor

It may be pointed out that human factor has not been shown in the equation of soil erosion (16.2) but C and P (cropping and management factor and conservation practice factor) representing exclusively human factors have been included in the equation of soil erosion as presented by FAO (equation no. 16.3). Since the accelerated soil erosion is the result of increasing impact of human activities on natural ecosystem, man has become the most important factor in the soil erosion equation and thus this equation may be restated as given below :

$$E = f\,(C, T, R, V, S\ldots\ldots\ldots H)\ldots\ldots\ldots(16.4)$$

Where E, f, C, T, R, V and S have the same meaning as shown in equation 16.2. H stands for anthropogenic factor or human interference.

Factors of Soil Erosion

As stated above the factors of soil erosion include the following :

(1) **climatic factors :**

(i) precipitation mainly rainfall
  (a) rainfall intensity
  (b) quantity of rainfall

- (c) duration of rainfall
- (d) rainfall distribution
- (e) terminal velocity of raindrops
- (f) kinetic energy

(ii) temperature (sunshine)

(iii) wind

(2) **topographic factors :**

- (i) relative reliefs
- (ii) gradient and slope segments
- (iii) slope profile length
- (iv) slope aspects

(3) **lithological factors :**

- (i) rock types
- (ii) chemical and physical properties of rocks

(4) **vegetation factors :**

- (i) types of vegetation cover
- (ii) density of vegetation
- (iii) nature of parent rocks

(5) **soil factors :**

- (i) soil erosivity
- (ii) soil erodibility

(6) **human factors :**

- (i) land use changes
- (ii) farm practice changes
- (iii) construction and building activities
- (iv) mining and excavation
- (v) management measures

(1) **Climate factors :** influencing runoff and soil erosion include precipitation mainly rainfall, temperature and wind. The intensity, amount (quantity), duration and distribution of rainfall are the most important components of rainfall factor which determine the nature and magnitude of soil erosion most. Large amount of rainfall (due to persistence of rainfall for relatively longer duration) with high intensity causes maximum soil erosion if other factros also favour soil erosion but high intensity of rainfall of short duration (and hence low amount of total rainfall) causes little erosion of soils. The magnitude of soil erosion caused by the parameters of rainfall is largely dependent on vegetation because vegetation determines infiltration-runoff ratio which ultimately determines the nature and magnitude of erosion. **Overland flow** is caused when rainfall intensity (rainfall intensity means total amount of rainfall received per unit time mainly per hour) exceeds infiltration rate (amount of rainwater percolating into soil horizons or ground surface per unit time). According to N. Hudson (1971) and M.A. Morgan (1969) rainfall intensities may go upto 225 mm per hour whereas infiltration rates range between very low value of 2 mm to very high value of 2500 mm per hour in different regions having varying environmental conditions but average values of infiltration rate common to many locations range between 5 mm to 150 mm per hour. Densely vegetated mainly forested areas allow maximum infiltration of rainwater because it reaches the ground surface slowly in the form of **aerial streamlets** through the branches and stems of trees and thus the resultant overland flow is either absent or is insignificant and hence soil erosion in the presence of forest cover is negligible. On the other hand, bare arable soils generate maximum overlandflow and allow least infiltration of rainwater because of compaction of the soils caused by the use of agricultural equipments (such as tractors, harvestors, combines etc.). This resutls in maximum erosion of soils which are exposed to falling raindrops in the absence of any vegetal cover.

The terminal velocity of raindrops (the constant velocity of raindrops, known as terminal velocity, is the result of equilibrium between the gravitational force and frictional resistance of the air) depending upon size, density and shape of the raindrops affects the nature and magnitude of soil erosion. On an average, the terminal velocity of raindrops increases as the size of raindrops increases. The standard large natural raindrops with diameter of about 5 mm have terminal velocity of about 9 meters per second. The momentum of the falling rain, known as **kinetic energy** of rain or **rainfall energy** is closely related to the intensity of rainfall. The kinetic energy of rain determines the power of raindrops to break down soil aggregates, to splash these split aggregates, to cause turbulence in surface runoff to carry away soil particles etc. The raindrops having high kinetic energy resulting from high intensity of rainfall detach soil particles from the aggregated mass at faster rate. Such type of soil erosion is called as **raindrop erosion** which is the most significant process of soil erosion on exposed soil surface. The surface runoff, having far less kinetic energy than the falling raindrops, transports the detached soil particles occasioned by raindrop erosion or splash erosion. Raindrop or splash erosion also helps in compacting the soil surface and plugging or sealing the pore spaces within the soils with finer particles such as clay. This compaction of soil surface reduces the infiltration capacity and increases surface runoff.

The kinetic energy or simply rainfall energy resulting from rainfall intensity also determines the rate of detachment of soil particles. High intensity rainfall has high erosive power because of high resultant kinetic energy whereas low intensity rainfall has low or little erosive power. Temperature also affects, though indirectly, the nature and rate of soil erosion mainly by wind. Alternate wetting and drying of soils causes hydration and dephydration of thin soil layer having montmorillonites. This process causes expansion (due to wetting and hence hydration) of soil particles which weaken the soils and develop myriads of tiny cracks in the outer surface of the soils. These cracks are filled with water during the next rains and thin layer of the soils becomes as soft as curd and slump down to be removed by surface runoff. Such mechanism of soil erosion becomes more effective and operative in those tropical and surbtropical areas which are characterized by wet and dry seasons. Wind becomes more effective agent of soil erosion in the arid and semi-arid regions during summer season of monsoon climate and during dry season of temperate climate. Wind also deflects raindrops and reduces (in the case of high speed wind) kinetic energy of raindrops.

(2) **Topographic factors** : include relative reliefs, gradient, slope segments, length of slope profiles, slope aspects etc. These factors are more important for geological erosion which is not our concern here but the slope is closely related with soil erosion and soil loss because steep gradient increases the flow velocity and kinetic energy of surface runoff which accelerates the rate of soil erosion and transport of eroded materials. The studies have shown that the rate of soil loss increases with increasing slope angle. Similarly, longer length of slope accounts for more soil erosion because of greater depth and velocity of overland flow than the shorter length of slope profile. A.W. Zingg (1940) has concluded that soil loss varies as the 1.4 power of the per cent slope if other environmental factors which control soil erosion remain more or less constant.

(3) **Lithological factors** : include rock types and their chemical and physical characteristics. These factors are, in fact, related to geological erosion of all types of geomaterials and are not related to soil erosion.

(4) **Vegetation factor** : is a dominant control factor of soil erosion becaue it (i) intercepts the rainfall through its canopy and thus protects the ground surface from direct raindrop impact, (ii) allows maximum infiltration of rainwater because the rainwater reaches the ground surface very slowly through the leaves, branches and stems as aerial streamlets, (iii) decreases sruface runoff because of more infiltration and reduces velocity of runoff because of obstructions offered by the stems of plants, (iv) reduces the rate of detachment of soil particles and their transportation, (v) its roots increase soil strength, granulation and porosity, (vi) acts as insulator of soils against high and low temperature and thus prevents the development of cracks, and (vii) markedly reduces the speed of wind and thus prevents soil erosion by wind.

(5) **Soil factor** : is related to the **erodibility** of soil which refers to the resistance of the soil to erosion or its vulnerability to soil erosion. Soil characteristics such as its physical and chemical properties (e.g. particle size distribution, structure, organic matter content, permeability, root content, shear strength, aggregate ability, tendency to surface crusting etc.) and management practices (such as crop management and land management) affect erodibility of soils which in turn together with eroding power of the processes (erosivity) determines the nature and magnitude of soil erosion.

(6) **Human factor** : has recently become the most important factor of accelerated soil erosion because his multi-facet activities change and modify almost all of the natural factors (as listed and discussed above) which control soil loss and soil erosion. The human activities leading to accerlerated rate of soil erosion may be grouped under three categories :

(i) **Land use changes** include removal of forest and grassland covers for various purposes viz. for increase in agricultural land, for meeting out ever-increasing demand of space for industrial expansion and urbanization, for the expansion of mining, for constructional purposes such as roads, rails, dams and reservoirs etc;

(ii) **Farm practice changes :** such as greater use of farm machines leading to greater impact of wheeled traffic on the land (use of tractors, harvestors, combines etc.), frequent changes in nature of farming such as shift from field crops to orchard farming or change from field crops to cattle ranching etc., and

(iii) **Management measures** include both crop management and land management. Ever-increasing application of farm machines and chemical fertilizers has largely modified the physical and chemical characteristics of soils.

Man induces and accelerates soil erosion by modifying the natural factors of soil erosion through his activities in a variety of ways as givne below :

➤ **Climatic factor is modified** by the removal of forest and grassland covers. Extensive clearnace of vegetation including both forests and grasses exposes the ground surface to the direct impact of raindrops. In the absence of vegetation cover there is no interception of rainfall and thus falling rain drops with high intensity and kinetic energy strike the ground surface of loose and unconsolidated materials. Consequently, the soil surface is pelted heavily by raindrops, soil particles are thrown up in the air and they are washed out after their return to the surface by surface runoff. Thus raindrop erosion or rain splash erosion is greatly increased which results in rapid and heavy loss of soils. The fine particles thrown up in the air by the impact of raindrops striking the surface resettle on the surface and seal the open pore spaces within the soils. This process results in the crusting of soil surface which markedly reduces the infiltration capacity of the soils and consequently increases surface runoff and overland flow which further erodes the soils at increased rate and transports the eroded materials.

➤ **Man modifies topography** by constructing terraces or contour bunds on hilly slopes for agricultural purposes, by quarrying and mining, by constructing roads, by digging canals and drainage ditches etc. The constructional works in urban areas accelerate soil erosion and increase sediment supply to the nearby rivers but this is limited to the period of construction only. Soil erosion stops after the construction is over.

➤ The physical and chemical properties of soils are changed by devegetation, ploughing, increased use of machines, application of fertilizers etc. Devegetation changes the content of organic matter in the soils and moisture and thermal conditions of the soils. Ploughing methods also largely affect the magnitude of soil erosion. For example, in the **'kachchar lands'** (vally-sides having rich alluvial soils being renewed every year because of recurrent floods in the Indian alluvial rivers) are generally ploughed transverse to the channels in order to get rid off excessive moisture (the farmers have little time for sowing 'rabi crops'-winter crops in India such as wheat, barley, gram, peas, mustard oil seeds etc. because of late withdrawal of flood water). The crops are not irrigated at all. With the result the ploughed furrows become dry and provide ready paths for surface runoff during next monsoon. Thus the channelled flow of overland flow erodes the loose soil materials easily and transports them to the river channel soon. The devegetation on the lower segments of hillsllope and cultivation of cut-over land acelerates the rate of soil erosion because of exposure of the ground surface to the direct impact of raindrops, faulty ploughing of the land and slope fator. Frequent use of heavy machines results in the cohesion and compaction of soil surface which reduces infiltration of rainwater and markedly increases surface run off which ultimately causes soil erosion through sheetwash or rainwash.

➤ Extensive grazing by sheep, goats and cattle also increases soil erosion. Besides, the soil properties are greatly modified through trampling by grazing animals.

It may be pointed out that natural processes of geological erosion whether of consolidated materials such as rocks or unconsolidated loose materials such as soils are so gradual but slow that these do not hamper the process of soil formation but the man-induced accelerated soil erosion is so rapid and immense that it disturbs the process of soil formation and thus there is enormous loss of this precious natural resource.

16.3 REGIONAL PATTERN OF MAN-INDUCED SOIL EROSION

It has already been pointed out that human activities such as replacement of natural forest and grassland covers by agricultural lands, felling of trees for commercial purpose, agricultural practices mainly ploughing, large-scale grazing of vegetation cover by sheep, goats and cattle, construction works such as construction of roads, dams, reservoirs and buildings, etc. have no doubt accelerated the rate of normal process of soil erosion very commonly known as geological erosion but it becomes difficult to ascertain the amount of soil erosion caused by human activities and normal processes of soil erosion separately. 'It is not known in any detail how much the present rate of total soil erosion in the world can be attributed to natural processes and how much is the result of man's influence. Nevertheless, some scientists have estimated that man is responsible for more than 50 per cent of the total erosion. Even if this average figure is rather a rough estimate, it is evident that in some environments man-induced erosion is definitely predominant' (Nature and Resources, UNESCO, Vol. 19, No. 2, 1983) such as monsoon regions, tropoical arid and semi-arid regions, Mediterranean regions and even temperate grasslands and forests where extensive forest and grassland clearance for agricultural and commercial purposes has augmented the rate of normal soil erosion by several times.

It is estimated that the world rivers carry about 40,000 cubic kilometres of water as surface runoff from the continents to the oceans each year. About 15 to 20 million tonnes of eroded soils are carried by the world rivers and are deposited in the seas and the oceans each year. Besides, 4 billion tonnes of fine materials are carried by the world rivers as suspended soluble materials. Based on this information it is calculated that each cubic metre of water from the continents reaching the seas and the oceans via rivers carries with it about 500 grams of sediments every year which are derived mainly through soil erosion.

The rate of soil erosion (both natural soil erosion and man-induced accelerated soil erosion) varies considerably from one climatic region to the other climatic region. Even in a single climatic region there is considerable variation in the rates of soil erosion because of the complexity of the factors which control soil erosion. For example, it has been estimated that the average rate of soil erosion on agricultural land in the U.S.A. is about 30 tonnes per hectare per year but 'strip mining often gives rise to a tremendous increase in erosion activity. In a mining district in southern Kentucky, United States, an annual sediment yield of more than 10,000 tonnes per square kilometre was recorded while undisturbed watersheds in the same area only yielded about 10 tonnes per square kilometre per year' (Nature and Resources, UNESCO, Vol. 19, No. 2, 1983). It has been reported that soil erosion during the constructional stages in the urban areas increases 20,000 to 40,000 times more than the normal rate of soil erosion in the undisturbed natural areas. The rate of soil erosion of 34,000 tonnes per square kilometre per year has been reported from Central China.

A study by Savindra Singh and S.P. Agnihotri (1987) has shown that the rate of soil loss by rill and gully erosion in the intervening zones between the Ganga plain and the foreland of Peninsular India is 2.35 million cubic metres per year in Jawa Block of M.P.

A study of gully erosion by Savindra Singh and Alok Dubey in the extreme southern part of Allahabad district from 1991 to 1994 revealed the fact that the rate of soil erosion from cultivated gullies (4,56,530 cubic meters per square kilometer) was much higher than the rate of soil loss from the natural gullies (3,87,800 m^3/km^2) covered with natural vegetation (Savindra Singh and A. Dubey, 2002).

Soil erosion caused by agricultural practices and extensive deforestation, clearance of grassland covers and overgrazing has assumed alarming proportion in tropical, subtropical and semiarid (savanna) regions. Extensive deforestation in the tropical evergreen rainforests has immensely damaged the physical and chemical properties of soils and has accelerated soil erosion by manyfolds. According to the report of the study of runoff and erosion under various covers of vegetation (viz. forest or ungrazed thicket, crop and barren soil) in five locations of Upper Volta (Ouagadougou), Senegal (Sefa), Ivory coast (Bouake and Abidjan) and Tanzania (Mpwapwa) in tropical region of Africa (as reported by A. Goudie, 1984) the mean annual runoff is 0.9 per cent, 17.4 per cent and 40.1 per cent of the total mean annual rainfall for forest or ungrazed thicket cover, agricultural fields and barren soil respectively. It is apparent from the above recorded data that mean annual runoff increases considerably from forest cover to barren soil. The rate of soil erosion also increases in the same direction but at much faster rate. The study shows that the average rate of soil erosion in the forest or ungrazed thicket cover, agricultural fields and barren soils in the aforesaid five locations of four tropical African countries is 0.09, 28.8 and 69.1

tonnes per hectare per year respectively. Thus it is apparent that the rates of soil rerosion increases from minimum rate of 0.09 tonne per hectare per year in the forested cover to 320 times under crop covers and 768 times under bare soil conditions. These figures clearly demonstrate the dominant role of man in accelerating the rate of soil erosion through his various activities mainly deforestation and agricultural practices.

The areas of deforested mountain slopes with steep gradients and semi-arid savanna lands of East Africa are the regions of most severe soil erosion caused by varied land use practices such as (i) extensive deforestation, (ii) overgrazing, (iii) over-cultivation, (iv) excessive collection of firewood, and (v) excessive burning of grassland, woodland and forest. The temperate grasslands have also been converted into extensive agricultural regions and thus are prone to excessive soil loss. The problems of accelerated soil erosion have been reported from different grassland biomes of the temperate grasslands of the world viz, Steppes of Russia, prairies of Canada and the U.S.A., Pampas of South America, Veld of South Africa and Downs of Australia. The studies of soil erosion and sediment yield under various land uses in the northern Mississippi, the U.S.A., (as reported by A.N. Strahler and A.H. Strahler, 1976) denote the fact that the surface runoff decreases considerably from cultivated crop fields (40 cm per year) through grazed pastures (38 cm per year), abandoned fields (18 cm per year), depleted hardwood (13 cm per year) to pine plantation (only 2.5 cm per year). It is evident from the above information that increasing vegetation cover from shrubs to forests increases infiltratin of rainwater considerably and thus surface runoff is reduced markedly. This trend of increasing surface runoff from forest cover to cultivated crop fields is also closely reflected in the increasing rate of soil loss and sediment yield in the same direction as average annual soil loss and sediment yield increases from the minimum value of 0.05 meteric ton per hectare for pine plantations through depleted hardwoods (0.2 metric ton per hectare per year),abandoned fields (0.3 metric ton per hectare per year), grazed pastures (36 metric tons per hectare per year) to very high value of 500 metric tons per hectare per year for the cultivated crop fields.It appears from the above statements that the rate of soil loss and sediment yield from cultivated crop field is 1000 times greater than the rate from forested areas. This clearly demonstrates the dimension of impact of human activities upon soil loss and sediment yield.

The studies of soil erosion under various land uses in eastern England (R.P.C. Morgan 1973-75) also indicate much difference in the rates of soil erosion under different land use categoreis. For example, the rates of soil loss over top slope, midslope and lower slope segments of bare soil cover are 7.10, 17.69 and 15.02 tons per hectare per year respectively. On the other hand, annual rate of soil loss is almost negligible in the areas of grassland covers (ranging between 0.17 to 0.68 ton per hectare per year) and forest covers (annual erosion rate ranging between 0.008 to 0.012 ton per hectare per year).

Extensive deforestation and overgrazing have led to severe soil loss in the monsoon lands of Asia in general and India is particular. The rill and gully erosion is most severe form of soil erosion in India. It is estimated that more than 37,00,000 hectares of agricultural lands have been rendered wastelands in India due to intense rill and gully erosion. Though deforestation (the percentage of forest cover to that of the total geographical area has decreased from 30 per cent to about 12 per cent) and consequent soil erosion has become a serious problem all over the country right from the nude and denuded hills of the North-Eastern Hill region in the east to bare Aravallis in the west and from extensively devegetated and sick Himalayas in the north to Nilgiris and Tamil Nadu plains in the south and from Western Ghats in the west to Eastern Ghats and coastal plains in the east, but soil erosion through rill and gully erosion has assumed alarming dimension in the states of Uttar Pradesh (12,30,000 hectares), Madhya Pradesh (6,83,000 hectares), Rajasthan (4,52,000 hectares), Gujarat (4,00,000 hectares), Maharashtra (20,000 hectares), Punjab (1,20,000 hectares), Bihar (6,00,000 hectares), Tamil Nadu (60,000 hectares) and West Bengal (1,04,000 hectares) where large areas have been engulfed by rill and gully erosion.

Extensive deforestation and terraced cultivation over U.P. Himalayas have accelerated the rate of soil erosion. The studies show that 24.99 million tonnes of top soils are eroded every year from the middle and Siwalik ranges of the Himalayas of Uttarakhand. Thus the mean annual rate of soil loss from the Uttarakhand Himalayas is 8.34 hectare metres per 100 square kilometres (8.34 ha m/100 km^2/year). It means that 0.834 mm thick soil cover is eroded every year from the catchment area of about

21,400 km^2 of the Ganga in the Uttarakhand Himalayas. In all 179.12 million tonnes of top soils are eroded every year from Uttarakhand and Uttar Pradesh and are disposed off by the Ganga river at Varanasi. Total amount of average annual silt carried away from Uttar Pradesh to Bihar by the Ganga System is about 23,456 hectare metres or 328.384 million tonnes and average annual runoff of the Ganga System between Uttar Pradesh and Bihar is about 21,328 thousand hectare metres or 213.28 thousand million cubic metres. The average annual silt-load factor of the Ganga's catchment area in Uttar Pradesh (674,535 km^2) is about 3.476 ha m/ 100 km^2/ year or 0.3476 mm per year. It means that every year about 0.3476 mm of top soil of Uttarakhand and Uttar Pradesh is eroded and carried away to the State of Bihar by the Ganga river system.

16.4 CONSERVATION MEASURES OF MAN-INDUCED SOIL EROSION

Since man-induced soil erosion has resulted into the loss of fertile soils and thus degradation of agricultural lands and rill and gully erosion augmented by extensive use of natural resources has rendered millions of hectares of land into wastelands. Sincere efforts are immediately required to halt accelerated rate of soil erosion caused by rill and gully erosion and to protect the cultivated farms from slow poisoning through rain splash and sheet erosion. Any viable soil conservation measure includes some basic objectives e.g. (i) protection of surface from raindrop impact, (ii) increase in the infiltration of rainwater, (iii) decrease in the volume and velocity of overland flow, and (iv) reduction in the erodibility of soils or increase in the resistance of soil against erosion by modifying physical and chemical properties of soils.

Since the mechanics and forms of soil erosion are divided into two major categories e.g. (i) slow rate of soil erosion mainly through rain splash, rainwash and sheetwash which are operative to greater extent in the cultivated areas, cut-over land and abandoned agricultural land, and (ii) accelerated rate of soil erosion through rill and guly erosion which is operative over the hill slopes cleared of vegetation covers, slopy grounds and riparian zones of the rivers, separate soil conservation measures and techniques are required to check soil erosion of the aforesaid two categories.

The soil conservation measures and techniques are divided into two categoreis e.g. (i) measure and techniques related to crop management, and (ii) mechanical protection and conservation devices and practices. It may be pointd out that any measure and technique of soil conservation must take into consideration the degree and duration of exposure of ground surface to rainfall because the exposure of larger areas in continuation for longer period to rainfall allows the raindrops to strike the soil surface with maximum kinetic energy and thus causes extensive soil loss through rain splash, rainwash and sheet erosion. It is, therefore, necessary to reduce the direct exposure of ground surface to raindrops. Before the initiation of any soil conservation measure and technique the following steps should be followed so that the implementation of soil conservation measures may yield satisfactory results : (i) extensive survey of the areas affected by soil erosion, (ii) classification of agricultural and forest lands according to land capabilities, (iii) identification and classification of erosion-infested areas into definite categories viz. areas of severe, moderate and low soil erosion based on intensity of soi erosion, and (iv) finalization of the priorities of soil conservation and land reclamation.

The soil conservation measures and techniques are broadly divided into two categoreis viz. (i) measures of crop management, and (ii) mechanical protection devices.

1. Measures of Crop Management

Measures of crop management to check soil erosion are basically applied in those cultivated areas which are under crops and are modeately affected by soil erosion. As stated above, the amount of surface area exposed and total duration of exposure of land surface to raindrops largely control soil loss. The proper management of growing of crops may decrease both, the amount of surface area exposed and total duration of exposure of surface area to rainfall. Crop management may also reduce runoff and overlandflow by increasing infiltration rate of rainwater. Increase in infiltration capacity and consequent reduction in runoff generation will automatically reduce soil erosion to great extent. The following measures of crop management may be adopted to reduce and retard soil loss through rainsplash, rainwash and sheetwash :

➤ **Proper crop selection** may markedly reduce surface exposure to rainfall and therefore may significantly reduce soil loss by restricting rainsplash hazard. For example, in India and in many tropical and subtropical developing countries agricultural fields are left open after the harvesting of 'rabi crops' (like wheat, grams, barley, peas, mustard oilseeds etc.) and are maintained as fallow lands throughout the rainy seasons (June to September). This traditional age old practice exposes the cultivated fields to rainfall throughout the rainy season (maximum surface exposure for longest duration) and hence maximum soil erosion first by rainsplash and then by rainwash and sheetwash results into enormous loss of good agricultural top soils. After the **'green revolution'** in India, no fallow land is maintained during rainy season in those areas where irrigational facilities are now available. The extensive cultivation of paddy crops in the areas which were previously used as fallow lands now has significantly reduced the period of exposure of the ground surface to rainfall but still there is long period of time between the harvest period of rabi crops and the transplanation of paddy crops. This period of no-crops and exposure to pre-monsoon rains and first rains during the outbreak of monsoon may be further reduced by growing leguminous crops during dry summer months and thus soil erosion may be significantly reduced. This measure may require additional supply of irrigational waters during hot and dry summer months.

➤ Such crops should be grown which cover maximum surface area and bind the soil particles together so that the ground surface may be protected from direct impact of raindrops and thus soil erosion may be reduced. It may be pointed out that total change of crops in view of their protective efficiency against soil erosion may not be possible and practicable because crop selection is governed by a variety of factors e.g. local demands, commercial value, market conditons, individual choice and preference, food value, water requirement etc.

➤ Alternatively, the sowing of crops should be so suitably adjusted that no ground surface remains exposed to the rainfall of high intensity for long period. For example, early transplantation of paddy crops may reduce rather eliminate exposure of ground surface to the outbreak of monsoon rains in the monsoon lands of Asia. Similar practice (early sowing of crops) in other tropical and subtropical countries may check soil erosion to great extent. According to N.W. Hudson (1957) early plantation of tobacco in Rhodesia has reduced soil erosion by 50 per cent.

➤ Practice of intercropping and mixed cropping may also prove beneficial to soil conservation becaue this practice does not allow simultaneous exposure of the whole field to rainfall as not all the crops mature and are harvested at the same time. Some crops mature early while others mature at later dates. Thus early maturing crops provide protection to late maturing crops. Such cropping is practiced in India during **'kharif season'** mainly in those areas where irrigational facilities are not available. Such cropping practice involves the cultivation of maize (corn), leguminous crops, arhar (a typical Indian pulse) and millet together in the same farm.

➤ **Stubble mulching** is another type of crop management which provides protection to the soil surface against raindrop erosion because the roots, leaves and stems of crops after the harvest of grains are left over in the fields and these parts of plants provide cover to the soil surface against falling rains and reduce soil-moisture evaporation. This practice besides being deterrant to soil erosion causes some other problems as well. For example, 'it leads to problems with seeding and the emergence of seedlings and to a proliferation of weeds and soil pests. A related system which is effective without those negative effects is **trash farming** in which chopped crop residue is spread and ploughed into the soil to produce an improved tilth in the surface soil' (R.B. Bryan, in K.J. Gregory and D.E. Walling, 1981).

➤ Maintenance of soils at high fertility level through the application of sufficient amount of chemical fertilizers increases the aggregation of soil which enhances infiltration capacity, reduces surface runoff and therefore decreases soil erosion. This practice is very much expensive and hence may not be followed by poor farmers of the developing nations. Secondly, increased use of chemical fertilizers causes progressive decrease in the content of organic matter in the soils. The presence of organic matter in the soils is very much necessary for the aggregation of soil particles.

➤ In order to offset the problem of declining organic matter content in the soil crop rotation must be practiced because it increases the fertility of the soils and raises the level of content of organic matter. Nitrogen fixing leguminous crops are very useful in raising the organic content of the soils. Several crop-combinations may be suggested for the purpose but the application of crop rotation in several developing nations may not be feasible because increasing pressure of food on agricultural land due to ever-increasing population may not permit the abandonment of continuous cropping or retirement of land from cultivation of crops.

➤ The land under active rill and gully erosion should be retired from active cultivation and grazing so that mechanical protective/conservation techniques may be applied to reclaim degraded land. The implementation of this scheme may also not be easily feasible and applicable because of several economic, social, technical and legal constraints. The farmers will not be ready for voluntary retirement of ravine-infested agricultural land because they do not have any other alternative source of food supply. This may be possible only when they are paid suitable compensatory free economic aid by the government agency for entire period for which the land is intended to be retired for reclamation and land treatment programmes. Will the governments be in a position to bear such extra huge economic burden mainly in the developing countries at the cost of other development programmes? Will the farmers be prepared to retire their land from active cultivation? These and many more quesitons remain unanswered mainly due to economic factor. Moreover, majority of the farmers in the developing countries are conservative, and are not readily prepared to adopt any beneficial innovative scheme.

➤ **Reforestation** and **afforestation** at large scale are the only effective measures which can reduce and check accelerated rate of soil erosion mainly over the hills which have been deprived of their dense cover of original forests through extensive deforestation. This cannot be achieved without the active cooperation of both, the governments and the general public. Social forestry may also be helpful in checking soil erosion directly and indirectly because it will reduce the pressure on forests for firewood and grazing.

2. Mechanical Devices

Mechanical devices include several techniques of ploughing, hoeing, cultivation etc. to check soil erosion mainly over slopy ground by reducing overland flow and increasing infiltration of rainwater and by reducing the velocity and transporting power of overland flow. The following techniques are used for this purpose :

(1) contour farming

(2) terracing

(3) control of gully erosion

(1) **Contour farming :** 'is a general term for ploughing, planting, cultivating and furrowing along the natural contour lines of sloping ground' (A.N. Strahler and A.H. Strahler, 1976). The ploughing of the slopy ground whether of a hillside slope or valley side slope (of alluvial rivers) parallel to the slope gradient or parallel to the contour of the slope generates ready-made flow paths for rainwater in the form of rills which carry huge amount of loose and friable soils down the slope during heavy rainstorms. In many of the countries the simplest mechanical protective device used to check soil erosion along the furrows is to plough the land transverse to the slope gradient. This method reduces overland flow because each furrow acts as a temporary dam. Thus numerous furrow-dams across the slope in descending order hold water, allow maximum infiltration of rainwater in the ploughed fields, reduce overland flow, discourage the formation of channels and rills and finally taboo soil loss through rill erosion.

This method of contour ploughing is useful only on gentle slopes of hillsides and valleysides which are affected by moderate intensity of soil erosion caused by rainstorms of also moderate intensity but if the rainstorms of very high intensity yield copious rainfall the furrow-dams are easily domolished and release of concentrated water causes speedy overland flow which erodes the soils more rapidly than the average normal overlandflow during moderate intensity rainstorms.

(2) **Tied - ridging :** is another form of mechanical protective device to check soil erosion which is practiced mainly in East Africa. Tied-ridging involves ploughing of the land across the slope gradient and construction of ridges across the furrows (i.e. parallel to the slope) or parallel to the general slope. In other words, the land is ploughed transverse to the slope whereas ridges are constructed parallel to the slope. This practice, thus, divides the field into several smaller basins which retard overland flow considerably and allow maximum infiltration of rainwater. Such technique is also

in use in the U.S.A. and is called **'basin-listing'** which is primarily meant for water conservation because this technique allows maximum infiltration of rainwater which increases the soil-moisture content.

(3) **Criss-cross ploughing** : of the valley sides of the alluvial rivers may reduce soil erosion to greater extent. In India velley-side slopes are ploughed down to the channel parallel to the general slope i.e. in transverse furrows to the river channel during 'rabi season' (winter season) and the farms are seldom irrigated. After the crops are harvested, the ploughed fields are baked hot in the scorching sunlight of summer months with the result loose soils become extremely dry. These dried soils are soaked with water during first summer shower and are slumped into the river bed by overland flow. This slumping of moistened soils results in the gradual silting of river beds. If the valley-side slopes are ploughed in criss-cross manner (first transverse to the slope and then parallel to the slope), the long furrows will be destroyed and therefore no furrow-channel will form. The absence of concentrated furrow-channel flow will retard rill erosion along the valley-side slopes.

(4) **Terracing (contour bunding)** : involves the construction of level-floored benches across the general slope gradient of hillslope bounded by earthen ridges or embankments which obstruct the downslope flow of water during rainstorms and retain water in the level floored small farms. In fact, the terraced farming or contour farming is intended to hold water (such terraces are called as **irrigation terraces**) or to check soil erosion (such terraces are called as **bench terraces**). Such techniques are used in those areas where soil erosion is severe because of steep slope gradients and heavy rainstorms e.g. hillslopes in South-Africa and South Asia. Mediterranean regions are also known for their level-floored bench terraces which are used for providing level ground for the cultivation of olive groves and vineyards. The hilly regions of India whether the Himalayas, or the Western Ghats or the North-Eastern Hill Regions are characterized by bench terraces. In majority of the cases these terraces have been greatly damaged because of release of more water from upslope region due to complete removal of vegetal covers. The construction of bench terraces must take into consideration the hydraulic characteristics of overland flow and slope gradient. The terraces should be closely spaced so that overland flow can be retarded and kept minimum. The construction of diversion drains to dispose off stormwater is an essential part of contour bunding. These drains are meant for diverting the rainwater of the areas outside the farms or say upslope areas of the terraced farms so that excess rainwaters may not pass through the terraces because if the excess water is not dispoed off by diversion drains, it may damage the embankments and may cause concentrated flow of overland flow with high velocity down the slope and thus may cause rapid rate of soil erosion.

(6) **Control of gulley erosion** : The fundamental difference between soil erosion caused by rainwash, sheetwash and rainsplash erosion on the one hand and by rill and gully erosion on the other hand is that the former (normal soil erosion) leads to the removal of rich surface soil in larger areas amounting to millions of tonnes of top-soils each year but the ground surface remains less dissected and is always suitable for the use of farm machinery whereas 'gullying, while actually removing less surface soil, can dissect land into minute uneconomic fragments, can totally distrupt the operation of machinery, and by lowering the water table, can reduce yields or pasture growth even where the soil is intact' (R.B. Bryan, in K.J. Gregory and D.E. Walling, 1981). In fact, the rill and gully erosion, if unchecked, converts very large areas into badlands which become totally unsuitable for cultivation and pasture. A large tract of intervening zone between the foreland of Indian Peninsula and the southern margins of the Ganga plain (for example, Chambal ravines) has been so greatly dissected by rill and gully erosion that the whole area has become a wasteland where dense network of gullies ranging in depths from 5 m to 80 m has engulfed millions of hectares of good agricultural land.

The control of gully erosion and the reclamation of ravinated land require a series of steps as follows :

(i) to reduce the flow of water in the gullies by constructing a series of **check dams** of earthen materials,

(ii) to trap the sediments behind the check dams,

(iii) to reduce the velocity of water flow in the gullies by reducing the channel gradient resulting from the responses of the first two steps as the sedimentation caused due to the trapping of sediments behind the check dams causes siltation of the gullies which in turn decreases channel gradient,

(iv) to lower the gradient of gully walls and gully heads,

(v) to stabilize the gully walls and gully heads through the plantation of vines, grasses, bushes, and trees and the development of pastures,

(vi) to stop the gully head-cut advancement by plugging the gully heads with stone filled iron nets,

(vii) to retire the land between two gullies from cultivation and to plant bushes and trees to protect the remaining land from gully erosion etc.

The problem of ravination in several parts of India (Himalayan foot-hill zones, intervening zones between the southern margins of the Ganga plains and the foreland of Indian Peninsula, Western Ghats, eastern coastal plains and other foot-hill zones of those hills and ranges which have been extensively deforested) is quite alarming and it has attained the status of national emergency. 'The alarming rate of ravination has caused and is causing colossal loss to agriculture, besides disturbing the hydrological balance. Although preventive measures including afforestation and ravine reclamation engineering works (contour bunding, plugging of gully head with stone-filled wire nets etc.) have been suggested by government agencies and professional geoscientists, "unfortunately ravine erosion, ravine management and ravine reclamation are all in part, social problems" (M.J. Haigh, 1984). 'The lack of environmental perception, poverty, land ownerships, fragmentation of land holdings and lack of liasion between government officials and the farmers limit the extent to which any reclamation measure can be applicable and effective' (Savindra Singh and S.P. Agnihotri, 1987).

16.5 MAN AND SEDIMENTATION

Sedimentation Processes and Global Sedimentation Problems

The sedimentation process refers to the deposition of sediments carried by running water in different suitable places like rivers, lakes and seas. In fact, the process of sedimentation is a comprehensive natural geomorphological process which operates through the chain of erosion of geomaterials (soils, unconsolidated surficial materials and parent rocks), transportation of these eroded materials called as sediments and deposition of these materials (sediments) in different parts of the river basins, lakes and seas. It is, thus, apparent that the basic source of the supply of sediments is erosion of loose and unconsolidated surficial materials as well as parent rocks. The normal rate of erosion of geomaterials by natural processes without being interfered by man's activities is called **geological/ natural erosion.** 'Slow removal of soil is part of the natural geological process of denudation and is both inevitable and universal' (A.N. Strahler and A.H. Strahler, 1976). On the other hand, **accelerated erosion** refers to the increased rate of erosion caused by various land use changes effected by man. Erosion and sedimentation under natural conditions are part of denudation system and do not cause any significant problem except some catastrophic events but accelerated erosion caused by human activities causes several environmental problems which adversely affect the plant and animal lives e.g. siltation of river beds and their consequent rise, shifting in river courses, increase in the frequency and magnitude of floods, reservoir sedimentation, filling of lakes and their degradation etc.

'**Sediment yield** is a technical term for the quantity of sediment removed by overland flow from a unit area of ground surface in a given unit time' (A.N. Strahler and A.H. Strahler, 1976) and this is usually expressed in tons per acre or metric tons per hectare. In other words, sediment yield refers to the total amount of sedimetns removed from a unit area (per square metre, per square mile/kilometre, per acre/hectare etc.) per unit time (usually per year). **Sediment load** of a river refers to the total amount of sediments of various sizes carried away by a river as **suspended load** and **bed load** wherein suspended load refers to the amount of fine sedimetns such as clay, silt and fine sands which are carried by the river in suspension off the bottom. The bed load comprised of sand, gravel, pebbles and cobbles is carried by the river water close to the channel floor. Mechanics and forms of soil erosion and factors and causes of soil erosion which contribute sedimetns to the sediment/ silt load of the rivers have already been discussed in the preceding sections of this chapter. It may be pointed out that huamn activities mainly land use changes (such as deforestation), urbanization, constructional works (such as construction of roads, dams and reservoirs), farming practices, overgrazing etc. have accelerated the rate of soil erosion at alarming rate which has been responsible for supply of enormous quantity of sediments to the world rivers. The increased sediment load of the major rivers of the world has caused several serious environmental problems and thus sedimentation in the different segments of the rivers, lakes, seas and canals has assumed global dimension.

It may be stated that the major river basins of the world mainly in the humid tropical and subtropical regions and semi-arid environment have become ecologically imbalanced because of sedimentation problems due to accelerated soil erosion caused by anthropogenic factors. The average annual water runoff of 40,000 km^3 from the continents to the oceans through rivers transports about15,000 million to 20,000 million tonnes of solid materials per year to the oceans besides 4,000 million tonnes of soluble material in suspension (Ake Sundborg, 1983, in Nature and Resources, Vol. 14, No. 2). One of the highest rates of soil erosion is reported from the Yellow basin of China wherein mean annual rate of soil erosion per square kilometre per year is 34,000 tonnes meaning thereby the loss of 34 kg of soil from every square metre of the river basin per year (reported by Ake Sundborg, 1983, based on the study of S. Gong and G. Xiong 1980). Savindra Singh and S.P. Agnihotri (1987) have reported that mean annual rate of soil erosion is 55.7 m^3 per hectare of land in the Tons riverine environment in Teonthar tahsil of Madhya Pradesh, India. 'Varios studies on soil erosion and sedimentation problem in different parts of the world indicate that the common factors for severe soil erosion are high intensity rains, seasonality of annual rainfall, loose and highly erodible soils, high reliefs, deforestation, faulty land use practices, construction works etc.' (Savindra Singh and, A. Dubey, 1989).

'The Amazon basin with largest catchment area (6,100,000 km^2) and highest mean annual water discharge (172,000 m^3/ sec-cumecs) carries less annual sediment load (850 million tonnes/year) than the relatively smaller basins like the Ganga (catchment area 9,55,000 km^2, mean annual water discharge 11,800 m^3/sec and mean annual sediment load 1,450 million tonnes/year) and the Yellow (catchment area 7,52,000 km^2, mean annual water discharge 1,379 m^3/sec, and mean annual sediment load 1,640 million tonnes/year) which clearly shows more dominance of vegetation in the Amazon catchment than in the aforesaid two basins (Ganga basin of India and Yellow basin of China). The total Ganga catchment representing a bit more than one-third of the Mississippi catchment of the U.S.A. (3,269,000 km^2) and only 1.27 times more than the Yellow catchment of China contributes about 5 times more sediments than Mississippi (annual sediment load being 300 million tonnes) and about 200 million tonnes less than the Yellow river. The sediment load per square kilometre per year of the Ganga, the Yellow, the Mississippi and the Amzon is 1,500 tonnes, 2,480 tonnes, 91 tonnes and 139 tonnes respectively. Thus the high rate of sediment load of the Ganga reflects the impact of deforestation of the source areas of the catchments of the Ganga System (the Himalayas and the foreland of Indian Peninsula) which has accelerated the rate of erosion of surficial materials (Savindra Singh and A. Dubey, 1987, p. 154). Table 16.1 presents the data of sediment load together with total catchment area, and mean water discharge of major rivers of the world.

Table 16.1 : Catchment areas, water discharge and sediment loads of some selcted rivers of the world

River	Country	Catchment area (km^2)	Mean water discharge (m^3/sec)	Annual sediment load (millon tonnes/ year)	Sediment load (tonnes per sq. km per year)
Yellow	China	7,52,000	1370	1640	2480
Ganga	India and Bangladesh	9,55,000	11,800	1450	1500
Amazon	Brazil	6,100,000	1,72,000	850	139
Brahmaputra	India & Bangladesh	6,66,000	12,200	730	1,100
Yangtze	China	1,807,000	29,200	480	280
Indus	Pakistan	969,000	5,500	435	450

Mississippi	U.S.A.	3,269,000	24,000	300	91
Irrawaddy	Burma	430,000	13,500	300	700
Red river	Socialist Republic of Viet Nam	120,000	3,900	130	1100
Parana	Argentina	2,305,000		90	38
Congo	Zaire	4,014,000	39,600	72	18
Pearl	China	3,55,000	8,000	70	260
Danube	Romania	816,000	6,200	65	80
Niger	Nigeria	1,081,000	4,900	21	19
Ob river	Russia	2,430,000	12,200	15	6
Po river	Italy	54,300	1,550	15	280
Don river	Russia	3,78,800	830	4.2	11
Rhine	Netherlands	160,000	2,200	2.8	17
Wisla	Poland	193,000	900	1.4	7

Source : Ake Sundborg, Nature and Resources, 1983, Vol 14, No.2

It appears from table 16.1 that the rivers of tropical, subtropical and Mediterranean regions carry larger amount of sediment loads than the rivers of the other biomes because of two basic factors viz. (i) large-scale deforestation, and (ii) enormous volume of water because of heavy rainfall in the catchment areas. Yellow, Ganga, Amazon, Brahmaputra, Yangtze, Indus, Irrawaddy, Red. Po rivers etc. tell the story of ever-increasing sediment loads because of accelerated rate of soil erosion consequent upon rapid rate of removal of vegetal cover in their catchments. The average annual sediment load per square kilometre for these river basins ranges between 139 tonnes and 2480 tonnes whereas the average annual sediment load of the rivers of colder climates ranges between 6 tonnes per square kilometre per year to 17 tonnes/km^2/year. It means that the problem of sedimentation of the river basins is mroe alarming in the tropical, subtropical and Mediterranean countries than those of the temperate and polar climates.

16.6 REGIONAL SEDIMENTATION PROBLEMS

It is evident from table 16.1 that the Ganga river carries the second largest amount of sediment load of 1450 million tonnes/year and annual rate of sediment load per square kilometre is also the second highest (1500 tonnes/km^2/year) in the world. This huge amount of sediments is contributed by the network of tributary rivers of the Ganga system through the erosion of the three physiographic regions of India viz. (i) the Himalayas, (ii) the Ganga plains, and (iii) the foreland of Indian Peninsula. The sediment load characteristics of the Ganga system in Uttarakhand, Uttar Pradesh of India illustrates the nature of acelerated rate of erosion conssequent upon deforestation in the source catchment areas of the tributary rivers of the Ganga mainly in the Himalayas.

The average sediment loads of major tributary stresms of the Ganga river at different sites in the state of Uttar Pradesh reveal the comparative rate of erosion of the Himalayas, the Vindhyan uplands (foreland of Indian Peninsula) and the Ganga plains of alluvial soils. The Yamuna river, the most significant tributary of the Ganga in Uttar Pradesh brings annually about 9,127 ha m (hectare metre) of sediment at Allahabad, the site of the confluence of the Ganga-Yamuna whereas the mean annual runoff, silt content by volume of water and silt load are 7.7 million ha m, 0.196 per cent and 2.493 ha m /100 km^2/year respectively. The average annual silt load of the Yamuna at Delhi site is only 1511 ha m and the average silt load factor is as high as 8.634 h m/100 km^2/ year. It means that the silt load factor in the upper reaches of the Yamuna (at Delhi site) is higher by 6.141 ha m/100 km^2/year than the silt load factor at its confluence (Allahabad) with the Ganga. Thus the higher silt load factor of the Yamuna in its upper reaches than its lower reaches reveals higher rate of erosion of the Himalayas. It may be pointed out that the catchment area of the Yamuna increases 2.1 times from Delhi (17,500 km^2) to Allahabad (36,600 km^2) whereas the silt load factor is reduced by 3.5 times. This is because of the fact that major tributaries of the Yamuna come from the northern foreland of Indian Peninsula and thus marked reduction in the silt load factor in downstream course of the Yamuna is because of slow rate of erosion of relatively resistant rocks of the Vindhyan uplands (northern foreland of Indian Peninsula) by the right-bank tributaries of the Yamuna (the Chambal, the Betwa, the Ken etc.). The source catchments of the Yamuna, the Ganga, the Ramganga and the Ghaghra (all are the tributaries of the Ganga) bring 704 ha m, 1913 ha m, 409 ha m and 6140 ha m sediments each year from the Himalayas to the plains respectively. The sediment load factors of these rivers at the foot-hill zones of the Himalayas are 6.132 ha m/100 km^2/year, 8.33 ha m/100 km^2/year, 13.025 ha m/100 km^2/year and 13.599 ha m/100 km^2/year respectively whereas the corresponding catchment areas of these rivers in the Himalayas are 11,422 km^2, 22,926 km^2, 3,134 km^2 and 46,145 km^2 respectively.

Out of total annual sediment load of 23,456 ha m (328.28 million tonnes) carried by the Ganga system and transported to the state of Bihar, the Himalayas, the Vindhyan uplands (norhtern foreland of Indian Peninsula) and the alluvial plains (Ganga plains) contribute 9,166 ha m (128.32 million tonnes), 8,423 ha m (117.82 million tonnes) and 5,867 ha m (82.13 million tonnes) respectively. Thus the Himalayas, the Vindhyan uplands, and the alluvial plains contribute 39 per cent, 36 per cent and 25 per cent of the total annual sediment load of the Ganga system in Uttar Pradesh. The different terrain components of Uttar Pradesh are eroded at an average rate of 0.347 mm per year.

Table 16.2 : Silt and runoff data at different sites on Ganga river in the State of Uttar Pradesh, India

Silt observation sites	Distance from the source (km)	Average annual runoff (thousand million cubic meters)	Average annual silt load (million tonnes)	Average silt load factor (ha m/100 km^2/year)	Average % of silt content by volume of runoff
Rishikesh	250	27.78	24.99	8.34	0.064
Kanpur	760	33.43	53.28		0.109
Varanasi	1115	116.99	179.72	2.48	0.116
Border of Uttar Pradesh and Bihar	1370	213.28	328.38	3.38	0.110

Table 16.2 reveals the increasing trend of sediment load, runoff and decreasing trend of silt load factor with increasing distances from the source at different hydrological centres located along the Ganga river. It is apparent from table 16.2 that average silt-load factor near the mountainous area at Rishikesh hydrological centre is quite high (8.34 ha m per 100 km^2 per year) in comparison to the hydrological sites in plain areas near Varanasi (2.48 ha m /100 km^2/year) and at the border of Uttar Pradesh and Bihar (3.38 ha m/100 km^2/year). This trend of silt load factor reveals the fact that the rate of soil erosion (soil loss) is quite high in the upper reaches of the catchment of the Ganga river (0.834 mm per year) in comparison to plain areas.

The Ganga system comprised of significant tributaries like Yamuna, Ramganga, Gomti, Ghaghra etc. and covering a total catchment area of 674,535 km^2 (out of total cathment area of 955,000 km^2) in the state of Uttar Pradesh including Uttarakhand carries an annual sediment load of 328.384 million tonnes and runoff of 213.28 thousand million cubic metres. The average silt load factor is 3.38 ha m/100 km^2/year and average per cent silt content by volume of runoff is 0.11. The top soil is eroded away at the rate of 0.3476 mm per year. The upper catchment of Ganga system in the Himalayas contributes 128.32 million tonnes of silt load of the entire Ganga system in th states of Uttar Pradesh and Uttarakhand. The Yamuna through its tributaries like the Chambal, the Betwa, the Ken etc. brings 117.83 million tonnes of sediments each year from the northern foreland of Indian Peninsula mainly from the world famous Chambal ravinous tracts where rill and gully erosion has resulted in the formation of dense network of gullies ranging in depths from 5 metres to 80 metres. On the other hand 82.13 million tonnes of top-soils are eroded each year from the alluvial plains of the state of Uttar Pradesh and are brought to the Ganga through its tributaries (Savindra Singh and A. Dubey, 1989).

'The high rate of fluvial erosion in the Himalayas is because of reckless felling of trees for the last 100 years or so. Huge amount of sediments unloaded by the Himalayan rivers in the plains causes siltation of the river beds, changes in the river courses, braiding of the channels and increase in the frequency and dimension of floods' (Savindra Singh and A. Dubey 1989). The study conducted by A. Dubey, (1985) has shown that the bed of the Ganga river at Allahabad has risen by 1.89 m between 1971 to 1978 while the study of S.S. Ojha (1987) has revealed that the bed of the Ganga at Allahabad has risen by 4.10 m during the last 80 years. 'Almost complete deforestation in the catchments of the Chambal, the Betwa, the Ken (tributaries of the Yamuna) and the Tons (tributary of the Ganga) has resulted into accelerated rate of soil loss through rill and gully erosion. The Chambal gullies range in depths from a few metres to 80 m whereas the depth of gullies in the tons riverine area (bordering the Ganga plain) varies from 5 m to 30m' (Savindra Singh and S.P Agnihotri, 1987). 'The most vulnerable areas for accelerated soil erosion are the intervening zones of the northern foreland of Indian Paninsula and theYamuna-Ganga plain and the foothill zones of the Himalayas. Markedly reduced discharge of water in the major rivers due to diversion of water through canals and lift irrigation schemes during lean flow period (October to June) is responsible for significant siltation in the river beds' (Savindra Singh and A. Dubey, 1989).

'The transfer of energy and geomaterials through the micro-pedogenic erosional processes functioning in and through the catchment area of the Ganga river system in the form of kinetic energy of the river water and entrained soil particles respectively between Uttar Pradesh and Bihar creates havoc in the agricultural productivity as well as per hectare yield of crops due to erosion of large amount of fertile soils from Uttar Pradesh. The problem of soil erosion because of micro-pedogenic erosional processes and increasing problem of deficiency of soil fertility due to washing away of the fertile top layer of soils is gradually increasing in Uttar Pradesh. This problem is also being aggravated due to increasing interference of man as geomorphic agent in the geocycle system of geomorphic environment (such as deforestation, overgrazing, faulty land use practices etc.). Afforestation, development of new grasses to increase the shear strength and aggregate stability of soils, scientific method of farm management, farmer's awarness programmes etc. can check and control the hazardous problem of soil erosion and increasing rate of siltation of river beds in Uttar Pradesh' (Savindra Singh and A. Dubey, 1989).

The Damodar river is another example of carrying ernormous amount of sediments derived from the acclerated rate of soil erosion of the forest-cleared land of Jharkhand and western West Bengal.

16.7 SEDIMENTATION AND MAN

Accelerated soil erosion is the most important source of sediment loads of the rivers. Natural processes of erosion, transporation of eroded materials by the rivers and their deposition in suitable areas of the river basins are of common occurrence and normally these do not initiate any major environmental problem but the ever-increasing activities of **'economic'** and **'technological man'** such as cultivation with greater use of agricultural implements, forestry, grazing, constructional works (such as construction of roads, dams, reservoirs etc.), mining, urbanization, accelerated rate of technical development etc. accelerate the rate of natural or geological erosion and thus man has become the most important source of sediment supply to the rivers. 'It is not known in any detail how much of the present rate of total erosion in the world can be attributed to natural processes and how much is the result of man's influence. Nevertheless, some scientists have estimated that man is responsible for more than 50 per cent of the total erosion' (Ake Sundborg, 1983). The human activities influence the channel aggradation (depositon of sedimetns in the river valley) in the following manner :

➤ The sediment load of the rivers is enormously increased because of phenomenal increase in soil erosion mainly through rill and gully erosion caused by deforestation, overgrazing, faulty farming practices, forest fires etc. Huge amount of sand, silt, gravels, pebbles and cobbles is carried away by the rivers as suspended load and bed load. As the amount of sediment increases, the rivers become overloaded and additional sediments are deposited as sandy colluvia and alluvia in different parts of the river valleys. Deposition of sediments in the beds (valley floor of the rivers) causes channel aggradation which results in gradual rise in the river beds. Rise in the river beds causes several serious environmental problems (these will be discussed in the subsequent sections). Reckless felling of trees renders hills and ridges nude. The exposed bare rocks of such nude hills and ridges are subjected to severe disintegration and decomposition by mechanical and chemical weathering processes. Consequently, weathered rocks are easily eroded away and are converted into coarse sands and gravels. When such coarse sands and gravels are deposited in huge amount in the valleys and riverine zones good fertile aggricultural soils are buried under heaps of enormous quantity of coarse sands and thus agricultural productivity is considerably reduced but the deposition of fine alluvium in the riverine zones also increases agricultural productivity because of the enrichment of soils.

Major engineering works such as construction of dams, man-made reservoirs or lakes behind the dams, artificial levees and embankments etc. also affect the transportation and deposition of sediments. Accelerated rate of soil erosion in the source catchment areas consequent upon deforestation, overgrazing and faulty cultivation methods release enormous quantity of sediments into the rivers and these sediments settle down in the reservoirs behind the dams. Reservoir sedimentation causes several problems to engineering works e.g. filling of reservoirs, damage to turbines, decrease in sediment load in the downstream section of the channel and hence scouring of valleys etc. (these will be elaborated later on).

➤ Mining operations supply huge amount of sediments to the rivers and thus increased sediment load causes aggradation of channels of the rivers in many places. 'Strip mining often gives rise to a tremendous increase in erosion activity. In a mining district in southern Kentucky, United States, an annual sediment yield of more than 10,000 tonnes/km^2 was recorded while undisturbed watersheds in the same area yielded only about 10 tonnes/km^2/year' (Ake Sundborg, 1983). Coal mining supplies enormous quantity of coarse sediments and causes large-scale aggradation of channels. Strip mining of coal in the Damodar Valley (India) releases huge quantity of coarse sediments every year. This additional amount of sediments increases the sediment load of the Damodar and causes filling of reservoirs of the Damodar Valley Authority (D.V.A.). 'Throughout the Applachian coal fields, channel aggradation is widespread because of the huge supplies of coarse sediments from mine wastes. Strip mining has enormously increased the aggradation of valley bottoms because of the vast surfaces of broken rock available to entrainment by runoff ' (A.N. Strahler and A.H., Strahler, 1976).

➤ Increasing urbanization and construction of roads mainly in the hilly areas contribute enormous quantity of very coarse sediments which increase the sediment load of the rivers and cause channel aggradation. The period of construction of buildings in the urban and industrial areas augments the supply of sediments to the nearby rivers and causes channel aggradation but this is not a perennial source of sediment supply. In fact, 'mining, urbanization and highway construction not only cause drastic increase in bed load, which cause channel aggradation close to the source but also increase the suspended load of the same streams. Suspended load travels downstream and is eventually deposited in lakes, reservoris and estuaries far from the source areas' (A.N. Strahler and A.H. Strahler, 1976).

16.8 SEDIMENTATION AND ENVIRONMENTAL PROBLEMS

Accelerated rate of soil erosion induced by human activities and resultant increase in sediment load of the major rivers of the world and rapid rate of aggradation of river valleys cause a series of environmental problems which introduce ecological imbalance and environmental degradation in the region concerned. These environmental problems include (i) loss of fertile agricultural soils and hence phenomenal decrease in agricultural productivity and total agricultural production due to accelerated rate of soil erosion, (ii) pollution of river water due to substantial increase in suspended sediment load and increase in sediment-water content, (iii) increase in the turbidity of waters of the rivers, lakes and reservoirs and even the sea shores where the rivers pour down immense quantity of sediments and thus cause adverse effects on aquatic life, (iv) reservoir sedimentation leading to silting of reservoirs and reduction in the storage capacity, (v) destruction of agricultural land, (vi) increase in the magnitude of floods, (vii) changes in river courses, (viii) drying of lakes etc. These after-effects of sedimentation and related aggradation require further elaboration.

(1) **Loss of Rich Agricultural Soils** : is basically caused by accelerated rate of soil erosion due to huamn activities. Faulty farming practices such as ploughing of the land parallel to the valley-side slope or traansverse to the river channel, furrowing across the contour of the hillslope or parallel to the gradient of hillslope, **jhuming** or **shifting** cultivation etc. cause rapid rate of soil erosion and thus the eroded materials are brought to the rivers by rainwash, rills, rivulets, gullies and streams. Continuous removal of soils from the hillslopes and valley-sides does not allow the soils to mature and thus the fertility of the soil is not stabilized rather it is continuously lessened and degraded. Unscientific terracing along the hillslopes cleared off the forest cover causes rapid rate of loss of rich soils which were formed in the past thousands of years under forest cover. Rill and gully erosion in the riverine tracts of the alluvial rivers causes loss of immense quantity of rich agricultural soils. For example, 2.35 million cubic metres of good agricultural soils are lost every year due to rill and gully erosion from the riverine tracts of the Tons river (Rewa district, Madhya Pradesh, India). A.N. Strahler and A.H. Strahler (1976) have reported that the average rate of soil loss from the wooded rural areas in the Washington-Baltimore region is 200 to 300 tons per square mile per year while it is 500 tons per square mile per year from the cultivated areas.

Deposition of coarse sands in the flood plains during the period of extensive floods buries fertile alluvial soils and renders the flood plains infertile and wasteland. This very often happens in those areas where the rivers become sluggish due to phenomenal increase in the sediment load mainly of coarse sands because of accelerated rate of weathering and erosion in the source catchment areas of the rivers where extensive deforestation has rendered the hills and ridges nude and thus has exposed the rocks to atmospheric processes. Rapid rate of deforestation of the Himalayas during the past 100 years or so and quarrying of limestones at certain localities (e.g. near Dehra Dun and Mussoorie in Uttarakhand Himalayas) have been responsible for choking the rivers with debris of various sizes in the intervening zones of the foot-hills of the Himalayas and the Ganga plain because of sudden fall in the transporting capacity of the rivers due to marked decrease in slope gradient and supply of huge quantity of coarse sands which have been deposited in the flood plains at many places.

(2) **Pollution of Waters** : Pollution of waters of rivers, lakes, and reservoirs due to excess sediment load particularly suspended load is the direct result of accelerated rate of soil erosion. In fact 'suspended sediment is a form of water pollution and may make water unfit for use in municipal water supplies and for certain industrial uses' (A.N. Strahler and A.H. Strahler, 1976). Excess amount of suspended load of clay and silt in the river water damages turbines which are used to generate hydroelectricity at the dam sites, increases turbidity of water which thus becomes harmful to aquatic life, reduces the quality of water for domestic and industrial uses etc. Harmful dissolved substances as ions in solution are brought to the rivers by surface runoff via rills, rivulets and streams. These dissolved substances adversely affect the physical and chemical composition of waters. Numerous ions in solution forms such as chlorine ions, sodium ions, potassium ions, phosphate ions etc. reach the streams and lakes via surface runoff from the agricultural fields which are very often treated with insecticides and pesticides and chemical fertilizers and from the urban sewage effluents. Some of the ions like phosphate and nitrate ions are rich nutrients to aquatic plants. These chemical sediments after reaching the rivers and the lakes in profusion cause phenomenal growth of some aquatic plants, the process is known as **'eutrophication'**. Excess amount of chemical sediments also causes deaths of various aquatic organisms.

(2) **Aggradation and Sedimentation** : Aggradation and sedimentation of river beds, reservoirs and lakes trigger off a series of chain effects. Excess supply of sediments due to accelerated rate of soil erosion makes the rivers overloaded and sluggish, with the result sediments are deposited in the valley floors and river beds. Continuous deposition of sediments in the river beds and their consequent gradual rise upward bring in the

following changes in the river regime. (i) Continuous aggradation of river valleys causes flattening of the valleys and braiding of river channels mainly of the alluvial rivers. Thus the braided channels become unsuitable for navigation. (ii) Aggradation of river valleys causes frequent changes in the river courses mainly in the areas of flood plains where the ground surface is almost flat. (iii) Rise in the river beds due to continuous siltaton reduces the water accommodating capacity of the river valleys on the one hand, and reduces the channel gradient on the other hand. These two side effects of siltation of river beds increase the frequency,magnitude and dimension of floods because the river water during occasional rainstorms easily overtops the river banks due to increased shallowness of the river valleys and spreads over larger areas. As the filling of river valleys due to continuous sedimentation goes on unabated, the valleys become shallower and flood water covers more and more areas every succeeding year. This trend is observable in all of the rivers of the Ganga-Yamuna plains of north India where the frequency and dimension of floods are increasing every year. The bed of the Ganga river has risen by several metres at numerous places in its middle and lower reaches. For example, 'the study conducted by A. Dueby (1985) shows that the bed of the Ganga has risen by 1.89 m within 8 years (1971 to 1978) which is evident from the fact that during 1971 the Ganga recorded maximum discharge of 58,377 m^3/sec with flood level (gauge level) at 86.46 m (ASML) whereas the flood level rose to 88.35 m (AMSL) with comparatively low discharge (53,877 m^3/sec) during 1978 which can be explained only in terms of silting of the Ganga bed by1.89 m. The study conducted by S.S. Ojha (1987) shows that the bed of the Ganga near Phaphamu (Allahabad) has risen by 4.10 m during the last 80 years (S.S. Ojha, Savindra Singh and R.C. Tiwari, 1989).

(4) **Sedimentation and Floods :** Taking out of substantial amount of water for irrigation purposes from the major alluval rivers of the Ganga-Yamuna plains (such as the Ganga, the Yamuna, the Ramganga, the Gomti, the Ghaghra, the Gandak, the Kosi, the Tista etc.) during lean period of minimum discharge reduces the discharge and velocity considerably and thus the overloaded rivers become sluggish and deposit the etxtra load of sand and silt in their beds. This siltation of river beds causes braiding of the river channels and meandering in the longitudinal courses. The greater frequency of well developed meanders in a river course reduces the velocity of water flow donwstream because of obstructions caused by the meander necks and thus overall discharge rate of water is considerably reduced. Thus meandering courses of a river retards the disposal of rainwater downstream and hence causes floods in the adjoining areas. Nearly all of the alluvial rivers of north India are characterized by meandering course and these (as listed above) have registered substantial rise in their beds because of continuous gradual siltation due to increased supply of sediments derived from the rapid rate of weathering and erosion of the Himalayas due to exposure of rocks to atmospheric processes consequent upon mass deforestaion. The Yamuna, the Ganga, the Ramganga, the Gomti, the Ghaghra, the Gandak, the Kosi etc. have become menace during every rainy season because of ever-increasing frequency, recurrence interval and magnitude of floods. The Kosi river has become notorious because of sudden changes in its courses.

(4) **Souring of River Beds :** Construction of dams on the rivers for irrigational purposes and for the generation of hydroelectricity allows the sedimetns to settle down in the reservoirs behind the dams. This results in marked reduction in the sediment load in the downstream section from the dam sites. Thus the underloaded rivers resort to scouring of their beds and banks which causes riparian decay and loss of agricultural lands, settlements and overall environmental degradation.

(5) **Reservoir Siltation :** Increased sediment load of the rivers due to deforestation and consequent accelerated rate of erosion has become serious threat to the man-made reservoirs because of rapid rate of siltation of reservoirs behind the dams. After the completion of seven dams and several reservoirs on the Damodar river and its tributaries (India) in 1950 severe soil erosion in the upper catchments of the river basin and the transportion of huge amount of sediments led to the rapid rate of siltation of newly constructed reservoirs in a very short period which was never expected while framing the project. The impounding of water in the reservoirs led to marked reduction in the volume of the dowstream from the dams and hence sedimentation was augmented in the Hooghly part of the Ganga delta. All these requrired dredging of the reservoirs and the Hooghly river. This costly undertaking of dredging of silted reservoirs and choked river channels due to excessive sedimentation still continues in many parts of

India and the world. In fact, reservior sedimentation has become a global environmental problem. 'The range in rates of reservoir sedimentation is very large. For about 1,000 small reservoirs in the United States with a storage capacity of less than 140,000 m^3 the average annual loss in capacity was 2.7 per cent. For large reservoirs with a storage capacity greater than 1,400 million cubic metres the coresponding value was 0.16 per cent. Many reservoirs around the world have had their usable capacity completely filled by sedimentation after only a few years of operation. An example is the Heisonglin reservoir, comparatively small reservoir in the loess area of China with a drainage area of 370 km^2 and annual sediment load of about 700,000 tonnes. The reservoir was completed in 1959 (Ake Sundborg, 1983) with life expectancy of 16 years but due to implementation of several corrective measures in the catchment area such as soil conservation measures and measures of sluicing sediments periodically through the dam, the life of reservoir has been estimated to have increased from initial estimate of 16 years to about 80 years.

The dams and storage reservoirs also modify the pattern of discharge of downstream section of the streams. The studies of inflow and outflow of water in and out of the reservoirs have shown that if the reervoirs are not full the peak discharge downstream may be reduced by 98 per cent and if the reservoirs are full to near capacity downstream discharge may be reduced by 50 per cent. 'Because reservoirs provide a sediment trap in which upto 95 per cent of the bedload and suspended sediment carried by the river can be retained, then it encourages scouring downstream of the dam. At the upstream end of the reservoir, sediment accumulation may be encouraged as the velocity of the water is reduced on reaching the impounded water body' (K.J. Gregory, 1981, in K.J. Gregory and D.E. Walling, 1981).

(6) **Siltation of Lakes :** is of very common occurrence due to sedimentation processes induced by human activities. Aggradation of intermontane basins in arid and semi-arid regions is a very common natural process but the aggradation of such basins has been augmented because of increased supply of sediments due to accelerated rate of erosion caused by devegetation of hillslopes. Many of the natural fresh water lakes of India situated in the Himalayas are being silted rapidly because of inflow of huge amount of coarse sediments each year. **Sukhatal** (dry tank/lake) and **Sariatal** (rotten lake) are a few typical examples of dead lakes of Kumaun region of Uttarakhand, India, because these have been completely destroyed by sedimentation of high magnitude. Even Naina lake (Nainital, India) and Bhimtal (Kumaun region, Uttarakhand, India) have registered rise of their beds by several metres. Bhimtal is surrounded by bare hills on all its sides, which are being eroded at fast rate and eroded materials are quickly transported to the said lake thus causing rapid rate of siltation of the lake.

(7) **Progradation of the Coast :** Sediments brought down by the rivers, if not deposited in their courses, are ultimately deposited in the seas to form deltas and marshy lands. The increased supply of sediments to the coastal areas by the streams some times, if other factors remain favourable, casues progradation of the coast land. At many places the sediments brought down by the rivers are picked up by sea waves and are reworked and redeposited at other places. This process enriches sea beaches in some places while causes deterioration of harbours due to siltation in other places. Nearly all of the major deltas of the world (such as Mississippi Delta, Nile Delta, Ganga Delta, Godawari Delta etc.) show the trend of their seaward growth at increasing rate.

16.9 CORRECTIVE MEASURES OF SOIL EROSION AND SEDIMENTATION

Erosion and sedimentation in river basins, reservoirs, lakes and coastal areas have become serious environmental problems of economic significance because these affect the economic development of a nation concerned. It is not only desirable but is also necessary to check soil erosion and lessen sediment load of the rivers and retard sedimentation process. Two-fold corrective measures are required to control the problems of erosion and sedimentation e.g. (i) to check accelerated rate of soil erosion because erosion is the main culprit of supplying sediments to fluvial processes mainy rivers, and (ii) to minimise the sedimentation and aggradation in different locations such as sedimentation in the river courses, flood plains, reservoirs and lakes.

Elaborate conservation measures of soil erosion, the main source of sediment supply, have been suggested in much detail in section 16.4 of this chapter. It is, therefore, not desirable to reproduce those corrective measures of soil erosion here again (see section 16.4 of this chapter). In brief it may be restated that the conservation measures, to be adopted to check accelerated rate of soil erosion, should include (1) **agricultural measures** such as selection of suitable and appropriate crops, maximum coverage of soil surface by crops, crop rotation programmes, intercropping and mixed cropping, stubble mulching, strip cropping, contour and criss-cross ploughing, conservation tillage, dry farming, proper use of chemical fertilizers, retirement of land under active rill and gully erosion from active cultivation for such period which may be required to restore the soils to their original status, afforestation and reforestation; (2) **mechanical protection devices** such as terracing, construction of earth ridges, diversion drains and channels, gully control structures, ditches with banks, bench terraces, check dams, several engineering methods to check rapid surface runoff and rills and gullies, plantation of trees and bushes at the gully heads and valley-sides of rills and gullies etc.

The following are effective measures to control erosion of river beds and riparian tracts :

(1) **Surface armouring**of river banks by :

- ➤ natural vegetation,
- ➤ plantation of trees and bushes,
- ➤ prevention of cultivation of valley-sides,
- ➤ placing of gabions (engineering structure of baskets filled with earthen materials),
- ➤ mattresses or rip-rap,
- ➤ embankment dykes,
- ➤ concrete bank walls just like a sea walls etc.

(2) **Engineering structures** to deflect or retard channel flow such as :

- ➤ fencing,
- ➤ pilling of boulders,
- ➤ construction of jetties,
- ➤ construciton of groyns of wooden, concrete etc.

17

NATURAL HAZARDS AND DISASTERS MANAGEMENT

17.1 ENVIRONMENTAL HAZARDS AND DISASTERS : MEANING AND CONCEPTS

Before attempting the discussion on natural hazards and disasters management it is imperative to define the following terms :

(1) extreme events,
(2) hazards
(3) disasters, and
(4) environmental stress.

EXTREME EVENTS

Those events or accidents, whether caused by natural processes or human factors, are called extreme events which occur very rarely and aggravate natural environmental processes to cause disaster for human society such as sudden tectonic movements leading to earthquakes and volcanic eruptions, continued dry conditions leading to prolonged droughts, floods, atmospheric disturbances, collision of celestial bodies, leakage of toxic gases, pouring of immense volume of petroleum from big oil tankers into the seas, natural and accidental forest fires etc. Extreme events fall into two categories :

(i) natural extreme events
(earthquakes, volcanic eruption, atmospheric disturbances, floods etc.)
(ii) anthropogenic extreme events
nuclear disaster, leakage of poisonous gases etc.)

ENVIRONMENTAL HAZARDS

Environmental hazards may be defined as those extreme events either natural or man-induced which occur rarely and exceed the tolerable magnitude within or beyond certain time limits, make human adjustments very difficult, result in colossal losses of property, human and animal lives, destruction of settlements and vegetation etc.

It may be mentioned that hazards have been differently defined as processes or causes which lead to extreme events, as natural or man-induced events which cause disasters, as a synonym of disaster etc.

As per definition of the UNO hazard is 'a potentially damaging physical event, phenomenon or human activity that may cause the loss of life or injury, property damage, social and economic disruption or environmental degradation.

It is apparent from the above UN definition that hazards are physical events i.e. causes or processes of disasters whether natural or man-induced.

Hazards have been accepted by the UN Commission for Human Settlements (UNCHS) as the probability of occurrences of damaging physical events which have potential for causing colossal loss to human health and wealth if they strike inhabited areas. Thus, hazards have the following characteristic features :

- hazards are natural or man-induced extreme events,
- hazards are physical events or causes or processes of disasters,
- hazards have potential for damaging different forms of life mainly human life,
- hazards represent latent conditions for future threats to all types of biota,
- hazards are of varying origins; of natural origin or of anthropogenic origin,
- hazards may or may not become disasters etc.

DISASTERS

Disasters, whether natural or anthropogenic, are sudden adverse unfortunate extreme events or hazards which cause great damage to human beings as well as plants and animals. Disasters occur rapidly, instantaneously and indiscriminately.

It is obvious from the above definition of disasters that these are the results or responses of environmental hazards. Thus, all the extreme events are hazards by not all the hazards are disasters. A hazard may become disaster only when it strikes the inhabited area. The following are the characteristic features of disasters :

- disasters are natural or man-induced hazards,
- disasters occur rapidly, instantaneously and indiscriminately,
- disasters are always viewed in terms of human beings i.e. severe damage to human life and property,
- the intensity of disaster is weighed in terms of the quantum of damages done to the human society,
- hazardous environmental processes always create extreme events but not all the extreme events become diasters; they become disasters when they occur in the inhabited area, and adversely affect human society. For example, a very strong tropical cyclone (typhoon, hurricane) becomes only extreme events when it occurs and dies in the midst of an ocean but it becomes disaster when it strikes the inhabited coastal area and inflicts colossal loss to human property and lives. Similarly, a volcanic eruption in uninhabited land or ocean is never disastrous but when it takes place in densely populated area, it becomes disaster,
- disasters are such uncontrollable extreme events that disrupt social structure and impair essential functions which are necessary to support human life system,
- disasters cause several socio-economic and health problems etc.

ENVIRONMENTAL STRESS

When the cumulative effects of environmental hazards, environmental disasters and other forms of environmental degradation and pollution become so immense that the tolerance limit of the natural environment to assimilate them is surpassed and the environmental balance is disturbed, the resultant state of the highly disturbed natural environment is called environmental stress. It is evident that the environmental stress represents extreme limit of environmental degradation where the homeostatic mechanism of the natural system becomes unable to assimilate the adverse effects of hazards, disasters and environmental degradation and pollution.

17.2 CLASSIFICATION OF HAZARDS AND DISASTERS

Environmental hazards and disasters are normally divided into the following two broad categories on the basis of main causative factors and their mode of origin :

(1) natural hazards and disasters
(2) man-induced (anthropogenic) hazards and disasters

Natural hazards and disasters are further subdivided into main and sub-categories as follows (see also fig. 17.1) :

1. Natural Hazards and Disasters

- **(1) Planetary hazards and disasters**
  - (A) Terrestrial or indogenous disasters
    - (i) volcanic disaster

    - (ii) seismic disaster
    - (iii) tsunami disaster
    - (iv) landslide disaster
  - (B) atmospheric or exogenous disasters
    - (i) abnormal or infrequent events
      - (a) cyclones disaster
      - (b) hurricanes disaster
      - (c) tornado disaster
      - (d) lightning disaster
      - (e) hailstorm disaster
    - (ii) cumulative atmospheric disasters
      - (a) flood disaster
      - (b) drought disaster
      - (c) cold wave disaster
      - (d) heat wave disaster
- (2) **Extra-planetary hazards and disasters**
  - (i) collision of meteors with the earth
  - (ii) mutual collision of meteors

2. Man-Induced Hazards and Disasters

- (1) **Physical disasters**
  - (A) reservoir-induced seismic (RIS) disaster
  - (B) man-induced landslide disaster
  - (C) accelerated soil erosion
- (2) **Chemical disasters**
  - (A) release of toxic chemicals
  - (B) large-scale leakage of petroleum from oil tankers
  - (C) nuclear tests and explosion
- (3) **biological hazards and disasters**
  - (A) failure of nuclear plants
  - (B) eutrophication
  - (C) insect swarms (such as locust swarms)
- (4) **technological disasters**
  - (A) failure of nuclear plants
  - (B) nuclear wars

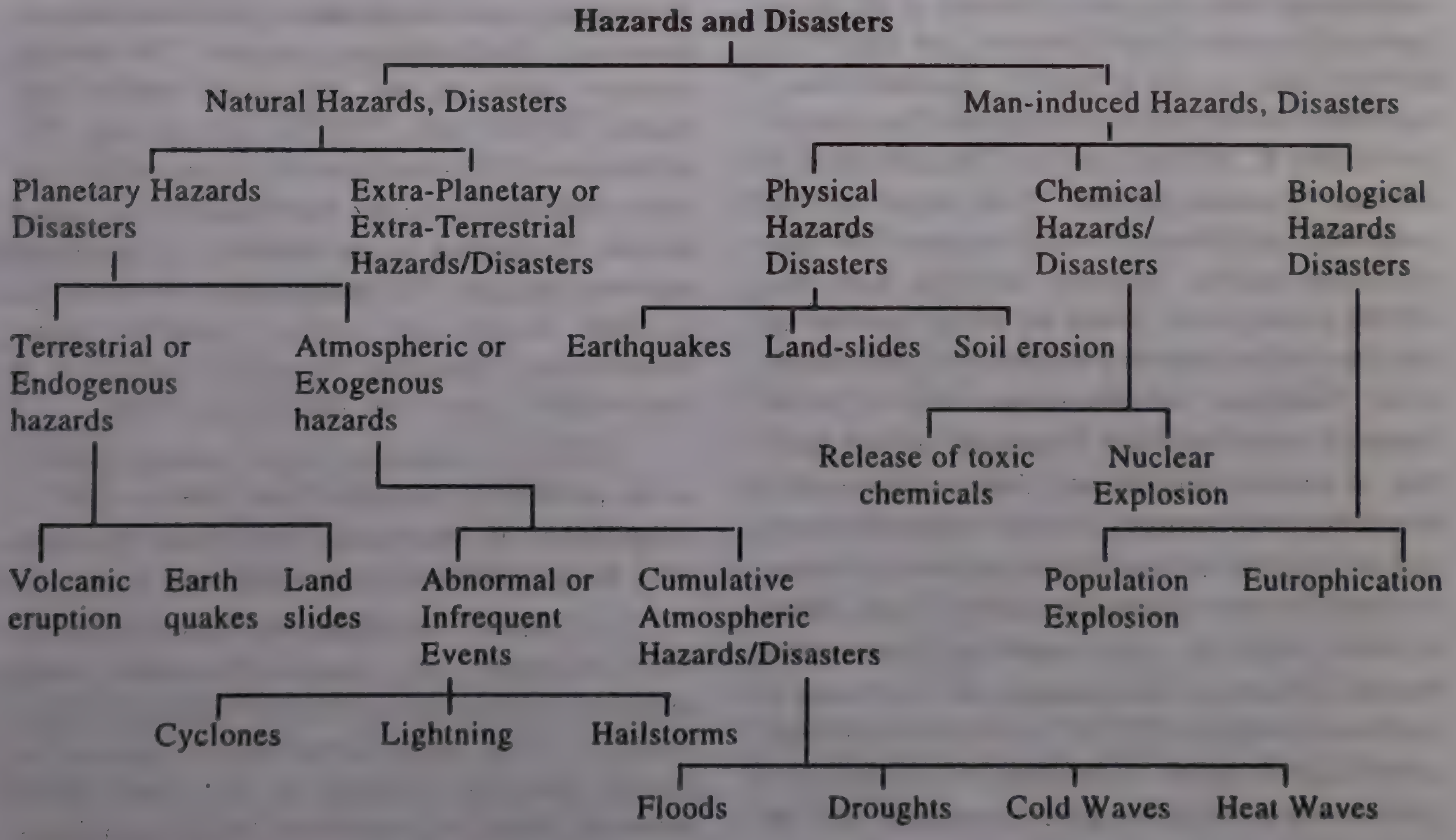

Hazards and Disasters
Natural Hazards, Disasters
Man-induced Hazards, Disasters
Planetary Hazards Disasters
Extra-Planetary or Extra-Terrestrial Hazards/Disasters
Physical Hazards Disasters
Chemical Hazards/ Disasters
Biological Hazards Disasters
Terrestrial or Endogenous hazards
Atmospheric or Exogenous hazards
Earthquakes
Land-slides
Soil erosion
Release of toxic chemicals
Nuclear Explosion
Volcanic eruption
Earth quakes
Land slides
Abnormal or Infrequent Events
Cumulative Atmospheric Hazards/Disasters
Population Explosion
Eutrophication
Cyclones
Lightning
Hailstorms
Floods
Droughts
Cold Waves
Heat Waves

Fig. 17.1 : Tabular classification of hazards and disasters.

It may be mentioned that now and onward only the term disasters would be used in this chapter.

The following discussion will focus only on natural disasters.

17.3 OVERVIEW OF NATURAL DISASTERS

It may be further pointed out that to majority of the people environmental hazards and environmental disasters are synonymous terms because these are related to extreme events in one way or the other. The present author, thus, also intends to use these two significant terms of environmental science as synonyms and hence only the term disaster will be used for further discussion.

Generally, the environmental disasters are natural and hence these are also termed as **natural hazardous processes.** It may be pointed out that the concept and perception of environmental disasters are closely related to their impacts on the organisms in general and mankind in particular. In other words, the natural sudden physical processes and events become disasters when people live close to a potential danger. For example, if an earthquake of more than 8 on Richter scale occurs in totally uninhabited area it is not a disaster at all but an earthquake even of lower intensity, say below 7 on Richter scale, occurs in heavily populated area, it becomes a severe hazard and disaster. For example, the October 8, 2005 earthquake of Muzaffarabad (in Pakistan Occupied Kashmir, POK) was of only 6.5 magnitude on Richter scale but was one of the most disastrous seismic disasters claiming more than 50,000 human lives. It may be further pointed out that it is not the frequency which makes any extreme event hazardous and disastrous rather it is the intensity, magnitude and dimension and the quantum of damage done by any event which make it hazardous and disastrous. It is also important to note that environmental hazards are not always destructive and disastrous themselves rather it is the effects of these events on other natural processes which become disastrous. For example, the Tajik area of the former southern U.S.S.R. 'is seismically a highly active region, shaken by upwards of 3000 tremors a year but these cause few direct casualties'. But 'the Tajik earthquake in the south of the former U.S.S.R. on 21 January, 1989, for example, was only of magnitude 5.5, but its timing unfortunately coincided with highly unstable slope conditions caused by high pore-water pressures resulting from snowmelt' (C. Embleton, 1989) and thus it became disastrous.

According to the report of the United Nations Disaster Relief Coordinator (UNDRO) about 90 per cent of all the reported natural hazards and disasters occur in the developing countries or in the Third World Countries. This observation may not be entirely true because natural disasters do not know any political or economic boundary and consideration. This observation may be because of the fact that most of the developing countries are located in the tropical and subtropical regions of the world where atmospheric processes very often cause numerous natural hazards and disasters such as floods, droughts, forest fires and of course volcanic eruptions and earthquakes wherein the last two are also more prevalent in other parts of the world. Rapid rate of urbanization, industrial expansion, agricultural development, population growth and social development are continuously accelerating the frequency and magnitude of natural hazards and disasters in the developing countries. 'Developing countries more or less chronically suffer from disaster. In one sense, they live with disaster. The achievements of development programmes have often been destroyed and their future plans halted because funds had to be diverted to relief and recovery activities. It should be noted, however, that a single disaster can strike a nation's social infrastructure, damaging its feedback system to an irrecoverable extent' (M. Hashizume, 1989).

Table 17.1 depicting major natural disasters in the developing countries from 1960 to 1987 as compilled by M. Hashizume (1989) from the works of G. Berg (1988) reveals the following facts :

(i) Table 17.1 includes only those disasters in which economic loss caused by extreme events exceeded one per cent of the GNP (Gross National Product) of the nation concerned. It appears that natural disasters dominate in the Third World countries. It may be pointed out that the conclusion of M. Hashizume is deceptive because the GNP is much higher in the developed countries than in the developing countries and therefore it would not be fair to calculate the magnitude of damages done by natural disasters on the basis of the GNP.

Table 17.1 : Major natural disasters, 1960-1987

Country	Event (disaster)	Month	Year	Deaths (of human beings)	Loss (US$ 10^6)	GNP (US$ 10^9)
Morocco	Earthquake	February	1960	13,100	120	12
Chile	Earthquake	May	1960	3,000	800	17
Yugoslavia	Earthquake	July	1963	1,070	600	45
Phillippines	Typhoon	November	1964	58	600	32
Italy	Earthquake	May	1976	978	3,600	352
Peru	Earthquake	May	1970	67,000	500	17
Nicaragua	Earthquake	December	1972	5,000	800	3
Honduras	Hurricane	September	1974	8,000	540	3
Guatemala	Earthquake	February	1976	22,778	1,110	9
Italy	Earthquake	May	1976	978	3,600	352
China	Earthquake	July	1976	242,000	5,600	280
Romania	Earthquake	March	1977	1,581	800	51
Yugoslavia	Earthquake	April	1979	131	2,700	45
Caribbean/USA	Hurricane	August	1979	1,400	2,000	...
Algeria	Earthquake	October	1980	2,590	3,000	47
Italy	Earthquake	November	1980	3,114	10,000	352
Greece	Earthquake	February	1981	25	920	33
Yemen	Earthquake	December	1982	3,000	90	4
Peru/Ecuador	Floods	April	1983	500	700	27
Fiji	Cyclone	March	1983	7	85	1
Colombia	Earthquake	March	1983	250	380	35
Chile	Earthquake	March	1985	200	1,200	17
Bangladesh	Cyclone	May	1985	11,000	...	...
Maxico	Earthquake	September	1985	10,000	4,000	136
Colombia	Volcano	November	1985	23,000	230	35
El Salvador	Earthquake	October	1986	1,000	1,500	4
Iran	Floods	December	1986	424	1,560	90
Vanuatu	Typhoon	February	1987	50	200	0.1
Ecuador	Earthquake	March	1987	1,000	700	10
Bangladesh	Floods	September	1987	1,600	1,300	12

Source : M. Hashizume, 1989 : ' The Present State of Natural Hazard; Identification and International Cooperation', in Aerospace Survey and Natural Disaster, Proceedings of the Symposium, Sept. 14-16, 1989 at ITC, Enschede, Netherlands (the present author also participated in the said symposium).

(ii) It is apparent from table 17.1 that earthquakes dominated over other natural disasters during the period 1960-1987 as out of total 30 extreme natural events causing economic loss of one per cent or even more of GNP of the nations concerned the events of the occurrence of earthquakes accounted for 66 per cent (20 in number). It appears that as regards the adverse/negative or destructive impacts of natural disasters earthquake disasters are the most serious and damaging ones.

17.4 : ASPECTS OF NATURAL DISASTER REDUCTION AND MANAGEMENT

The processes of reduction and management of natural disasters include the following aspects :

1. **Components (elements) of disaster reduction and management**
    - (1) hazard analysis
    - (2) vulnerability analysis
    - (3) risk analysis
2. **Stages of disaster reduction and management (PMP)**
    - (1) **Pre-disaster stage**
        - (a) **disaster preparedness (P)**
            - (i) level and nature of disaster preparedness
            - (ii) disaster research
            - (iii) disaster prediction
            - (iv) disaster warning system (DWS)
            - (v) disaster education
        - (b) **disaster mitigation (M)**
        - (c) **disaster prevention (P)**
    - (2) **Post-disaster stage**
        - (a) **relief measures (R)**
            - (i) social response
            - (ii) participation in relief work
            - (iii) relief materials
            - (iv) execution of relief work
        - (b) **rehabilitation (R)**
        - (c) **disaster recovery (R)**

Before attempting discussion on stages (phases) of natural disaster reduction the following terms as basic components of the processes of disaster reduction need explanation :

1. hazard analysis
2. vulnerability analysis, and
3. risk analysis

HAZARD ANALYSIS

The analysis of different types of hazards with previous history of occurrences and likely occurrences in near future in a region or locality is a prerequisite condition for any purposeful management plan for natural disaster reduction. The hazard analysis involves the histogenisis of different hazards, nature and mode of occurrence of a particular hazard in a specific region or locality with the following objectives :

Objectives
- to ascertain the number of hazards, likely to occur
- to ascertain the degree of intensity and severity
- to understand the likely adverse effects of a disaster on human society
- to understand the mode of occurrences of different hazards

A set of factors related to a particular hazard are taken into account to present detailed information which may be helpful in the reduction and management of natural disasters. The following factors are considered in compiling information system of a hazard which may lead to disaster :

- ➤ frequency of hazardous event, the frequency may be year-wise and season-wise,
- ➤ recurrence intervals of hazards of varying intensities and magnitudes,
- ➤ occurrence duration of each hazard,
- ➤ intensity and magnitude of hazard in terms of speed,
- ➤ severity of hazard in terms of quantum of likely adverse effects on human community,
- ➤ degree of predictibility of hazards,
- ➤ timely forewarning about the likely occurrence of a particular hazard,
- ➤ degree of manageability of a particular hazard etc.

The hazard analysis also includes the consideration of hazard types and their occurrences. On the basis of speed of movement hazards are divided into the following two major categories :

Hazards
- slow on-set hazards and disasters (e.g. drought, sea level rise)
- rapid on-set hazards and disasters (e.g. lava flow, earthquake, tsunami, tornado etc.)

Hazards may also be divided on the basis of duration of hazards and disasters as follows :

Hazards
- Short-duration hazards and disasters (e.g. tornado, avalanch, lava flow, landslides etc.
- long-duration hazards and disasters (e.g. floods, droughts etc.)

DISASTER VULNERABILITY ANALYSIS

In environmental science vulnerability refers to capable of or susceptible to a particular hazard and disaster. Question arises as to who is susceptible to a disaster? The answer is, it may be spatial unit (be it a specific location, or a region or a country or even larger area), a physiographic unit (e.g. mountainous area, flood plain, coastal area, marine ecosystem etc.), human community, plant community and animal community.

The WCDR (World Conference on Disaster Reduction, 2005) has adopted the following definition of vulnerability :

Vulnerability denotes the "conditions determined by physical, social, economic and environmental factors or processes, which increase susceptibility of a community to the impacts of hazards. Vulnerability is thus the probability of being damaged, destroyed or lost because of a natural hazard." "Vulnerability is far from being a static process; it is a dynamic process that keeps on changing the probability of process of loss and damage of all the elements exposed to disasters."

Elements of Disaster Vulnerability

Vulnerability to a particular natural hazard or disaster comprises a set of components which help in the identification and determination of nature and types of hazards and disasters. Such vulnerability elements (components) or factors include the following :

- hazard/disaster name, such as earthquake, cyclones, volcanic eruption, floods, droughts, avalanches, landslides, tsunami etc.
- spatial unit such as a particular locality, a region, a country etc.: examples, flood plains, coastland, mountain slope, ice caps, islands etc.
- vulnerable community, such as human community, plant community (a forest fire may destroy a large chunk of valuable forest area), animal community, both terrestrial and marine, including micro-organisms.
- speed of hazard, such as rapid onset of a natural hazard (e.g. tsunami, earthquake occurrence, lava flow, tornado etc.), slow onset of a natural hazard (e.g. drought, sea level rise etc.)
- duration of hazard, short-period quick impacts (e.g. tsunami, tornado, seismic events etc.), long-period slow but widespread impacts (e.g. floods, droughts, sea level rise etc).
- resistibility of materials of physical structures such as different types of buildings in varying locations (e.g. hillslopes, flood plains, low coastlands etc.), bridges, roads, rail tracks etc.

Vulnerability Typology

On the basis of elements of hazard/disaster vulnerability, the following vulnerability types may be identified :

1. **Individual hazard vulnerability**
   (i) volcanic vulnerability,
   (ii) seismic vulnerability,
   (iii) tsunami vulnerability,
   (iv) hurricane vulnerability,
   (v) tornado vulnerability,
   (vi) cyclone vulnerability,
   (vii) typhoon vulnerability,
   (viii) flood vulnerability,
   (ix) drought vulnerability,
   (x) landslide vulnerability,
   (xi) El Nino vulnerability, etc.
2. **Spatial vulnerability (vulnerable area)**
   (i) local area vulnerability (vulnerable locality)
   (ii) regional vulnerability (vulnerable region),
   (iii) country vulnerability (vulnerable country)

(iv) global vulnerability, such as sea level rise, etc.

3. **Infrastructural vulnerability**

(vulenerable infrastructure)

(i) vulnerable water supply system
(ii) vulnerable transport system
(iii) vulnerable communication system
(iv) vulnerable electricity supply system

4. **Community vulnerability**

(vulnerable community)

If the aforesaid vulnerability types are combined, these may be grouped into the following two categories :

Vulnerability types < physical vulnerability
social vulnerability

The community or social vulnerability includes the consideration of susceptibility of a particular community or social group to a particular disaster (for example, the fishermen community living in the close proximity of seas is most susceptible to the adverse effects of atmospheric storms and tidal surges, tsunami etc.); degree of human resistance and adaptation to disaster; level of social interactions and social adjustment to a disaster; psychological set up of individuals and society towards the occurrence of a hazard and consequential disastrous impacts; level of community cooperation in rescue and rehabilitation programmes etc.

Geographic information system (GIS), aerospace survey and satellite images help considerably in identifying and mapping of vulnerably areas, in obtaining historic information gathered from local people and transmitting such information to the researchers to better model the frequency and magnitude of events in an area. The detailed analysis of the vulnerable areas affected in the past and likely to be affected in near future by a particular hazard and disaster, of mass data set regarding the frequency, recurrence intervals of major events, magnitude and severity of hazards and disasters, physical, infrastructual, community and social vulnerability, social and governmental reactions and responses to hazards and disasters, adjustment of society to the hazards and disasters is of vital importance in the mitigation and reduction and future management of disasters.

DISASTER RISK ANALYSIS

Disaster risk is defined and viewed differently as follows :

A disaster risk is defined as likely adverse impacts of a particular hazard on different aspects, such as social, economic, political, medical, psychological etc., of human society.

"A risk (of hazard) is the probability that a hazard will happen or, more precisely, the likelihood that an event will coinside with elements which can be affected" (C.J. Barrow, 2005).

Since hazard/disaster risk is a probability of likely adverse impacts of a particular hazard on society, it is full of uncertainties in terms of magnitude and severity of a hazard, speed, quantum of likely damage, duration of persistence of disaster etc.

Disaster risk has different connotations and definitions in different disciplines e.g. environmental science, ecology, economics, engineering and technology, toxicology etc. A few examples are given below :

According to common connotation disaster risk is defined as :

(H) hazard x vulnerability (V)

or

According to engineers and technocrats disaster risk becomes the product of the following :

(P) probability (of the occurrence of a hazard) ×
(C) consequences (of a hazard)

or

P × C

Hazard/disaster risk is viewed in terms of human health and wealth; or it is viewed in terms of environment and nature.

The risk management, very significant aspect of natural disaster reduction and management, includes the following aspects :

- risk identification,
- risk assessment,
- risk perception assessment,
- determination of risk magnitude,
- risk communication (risk information),

- risk responses and risk takers,
- risk acceptability,
- risk avoidance,
- risk mitigation, etc.

Disaster risk assessment involves the following :

- assessment of vulnerability of a society, a locality, plant and animal communities,
- assessment of ability of resistance of system to a particular hazard/disaster,
- assessment of ability of resilience of a system, affected or to be affected such as humans, plants and animals, to recover from the damages done by a particular disaster,
- risk-cost-benefit evaluation,
- assessment of vulnerable localities
- assessment of vulnerability of different sections of society to a particular hazard, disaster etc.

Disaster risk assessment, though a significant aspect of disaster reduction and management, is an uphill task because it becomes more or less subjective (in case of voluntary risk assessment) and qualitative as it becomes difficult, and some times impossible, to obtain authentic and ample data of risk aspects.

Some parameters have been found out to determine magnitude and severity of natural hazards, such as **Richter** and **Marcali scales** to measure the intensity and severity of earthquakes; **Fuijita scale** to measure the severity and magnitude of damage of tornadoes; **Saffir-Simpson hurricane damage scale** (5-point scale, minimum damage, moderate damage, extensive damage, extreme damage and catastrophic damage) etc.

It may be pointed out that it is not the magnitude of a hazard that matters in terms of risk of damage rather it is the vulnerability of the locality and community to a particular hazard that matters more. For example, the inhabited hillslopes are more vulnerable to earthquakes. The earthquakes of Uttar Kashi (Uttarakhand, India) (6.6 magnitude on Richter scale, 20 October, 1991) and Muzaffarabad quake (POK, 6.5, October 8, 2005) in Pakistan Occupied Kashmir were of moderate intensity but they inflicted heavy loss of human lives and property. Further, the building materials also determine the magnitude of risk by earthquakes, for example, Latur (Maharashtra, 6.3, September 30, 1993) quake was also of moderate intensity but killed more than 11,000 people. The people living on the hillolopes are more vulnerable to seismic events and hence are liable to maximum risk. Likewise, inhabitants of coastal areas in general and fishermen communities in particular have maximum risk of being adversely affected by cyclonic storms, tidal surges and tsunami. The densely populated flood plains of alluvial rivers are most vulnerable to recurrent severe floods and hence are in maximum risk and threat zone.

Disaster communication is in fact a warning system of the probable occurrences of hazards and disasters. This is also called **risk information** which has two basic components as follows :

(1) risk communication system or transmission of disaster risks information to different segments of society, government and non-governmental organizations (NGO), and

(2) takers (receiver) of disaster risk information i.e. vulnerable and threatend sections of society.

This aspect will be discussed later in this chapter but it may be emphasized that the effects and responses of disaster risk warnings depend on the types of media through which risk assessment and warnings are communicated, sources of risk information, credibility and acceptability of risk information, nature of takers (recipients) of risk information, nature of responses and adaptability to risk information from different segments of society etc.

It may be mentioned that perception of disaster risks and disaster threats varies from person to person and from community to community. Some times some people become disinterested towards risk and threat warnings inspite of high magnitude and high degree of risk associated with likely occurrence of a hazard. Some times certain people become indifferent and complacent about the risk warnings.

It may be sumarized that the basic elements of natural disaster reduction and management include the study and analysis of the nature of hazards in terms of their origin, magnitude and severity; **vulnerability** of an area or segments of society or both to a particular hazard and disaster; risk assessment of probable occurrence of a particular hazard and disaster, risk and threat perception and risk information system; resistance or ability of a system, may it be a social system (community) or biological community (plants and animals), or physical system (terrain characteristics, infrastructural facilities etc.) to withstand the furry of the severity of a hazard and disaster; **resilience** of human society and environmental system to recover from the destruction done by a hazard and disaster; human responses and adjustment to a particular hazard and disaster.

17.5 STAGES OF NATURAL DISASTER REDUCTION AND MANAGEMENT

Basically, the occurrences of hazards and disasters are studied in three stages as follows :

1. Pre-disaster stage,
2. On-disaster stage, and
3. Post-disaster stage.

Alternatively, these three stages are termed as :

1. Anticipatory stage (anticipation of disaster),
2. Participatory stage (participation of community in disaster mitigation), and
3. Recovery stage (relief work, rehabilitation and recovery from the disaster).

These three stages of natural disaster reduction and management are also termed as :

1. Preparedness stage (P),
2. Mitigation stage (M), and
3. Recovery stage (R).

These are called **PMR stages** wherein each stage or step is linked with other stage or step. These three stages of natural disaster reduction and management (NDRM) may be combined into two broad stages as follows :

1. Pre-disaster stage < preparedness (P)
mitigation (M)
prevention (P)

These are called **PMP stages** wherein first (P) and second (M) stages lead to the third stage (P). In other words, the primary goal of natural disaster reduction is to minimise the adverse impacts of natural hazards on human society and thus activities undertaken under first two steps (preparedness and mitigation) are prerequisite requirements for prevention of damages done by a disaster.

2. Post-disaster stage < relief (R)
recovery (R)
rehabilitation (R)

These relief works, recovery steps and proper rehabilitation of affected people are called **Three 'R' steps** of post-disaster management of disaster reduction and management.

PRE-DISASTER STAGE

Pre-disaster stage of disaster reduction and management aims at informing the people of the area to be affected by a hazard and disaster well in advance; to make the community prepared and mently ready to face any sort of eventuality through various measures; to minimize the probable adverse effects; and to prevent the occurrence of a hazard or atleast to weaken the furocity thereof or to divert the path of movement of storms such as hurricanes, other tropical cyclones etc. Thus, the pre-disaster stage includes the following three major steps (known as PMP steps) :

1. disaster preparedness (P)
2. disaster mitigation (M)
3. disaster prevention (P)

The pre-disaster stage primarily aims at reducing the adverse impacts of hazards and disasters by adopting certain measures. There are certain hazards, the time of occurrence of which cannot be precisely known before hand such as seismic events (earthquakes), volcanic eruption, tsunami, tornadoes, but there are certain hazards and disasters whose occurrence time can be known well in advance such as tropical cyclones, floods, droughts etc. If a long-range planning is formulated and executed, the occurrences of such hazards though cannot be prevented but their adverse impacts can be reduced to a certain degree.

It is, thus, necessary to discuss PMP steps as preparatory measures to manage hazards and disasters.

1. DISASTER PREPAREDNESS (P)

Preparedness means necessary arrangements to meet any eventuality if a hazard strikes a locality and community. This involves the study of the vulnerability of a locality or a region to certain hazards and disasters; to identify hazards and to study the nature, severity, and mode of occurrence of particular hazard; to assess the risks of individual hazard; to determine the magnitude of a hazard; and quantum of damage to be done by such hazard; to prepare vulnerability maps of the concerned area; to educate the people about the nature and likely adverse impacts of a hazard through various methods; to educate the people about avoidance of hazards and taking safety measures in the event of occurrence of a disaster etc.

It is apparent from above discussion that primary aim of disaster preparedness is to initiate such steps and measures, pursue such activities and formulate and adopt such action plans which can reduce the adverse impacts of disasters in terms of loss of lives and property of the human society to be affected by a disaster. In fact, disaster preparedness refers to gear up all government machineries, individuals and communities, non-governmental organizations, social groups, activists etc. to be in a state of readiness and fully equipped in the event of a disaster. The following measures should be adopted to make the disaster preparedness effective :

- **disaster research**, which includes the following :
  - (i) mapping and preparation of disaster prone (vulnerable) areas and risk magnitude zone maps,
  - (ii) study of nature (types, characteristics, origin), magnitude and severity of hazards and disasters,
  - (iii) risk assessment of disasters,
  - (iv) study of past history and recurrence intervals of hazards and disasters,
  - (v) study of psychological, economic and social implications,
  - (vi) prediction techniques etc.
- **preparation of contingency plans** and creation of infrastructural facilities for relief work, recovery and rehabilitation activities to be followed in the post-disaster stage of disaster management. The needed infrastructural facilities include the following :
  - (i) rescure operation,
  - (ii) shelter and food,
  - (iii) safe drinking water,
  - (iv) electricity supply,
  - (v) transport system,
  - (vi) language efficiency,
  - (vii) medical facilities etc.
- **adaquate support systems** are required to meet out the requirements of above mentioned infrastructural facilities. The following support systems are required :
  - (i) financial support,
  - (ii) material support,
  - (iii) equipment support,
  - (iv) administrative support,
  - (v) medical support,
  - (vi) social support, etc.
- disaster education and awareness
- disaster management training programmes
- disaster warning system
- dissemination of disaster information and knowledge
- formation of disaster reduction plans and projects for reducing poverty of the affected people due to loss of their life support systems, and disabilities caused by the disasters
- involvement of NGOs, business sectors, entrepreneurs, social activists etc. in effective execution of rescue operation and rehabilitation programmes
- preparation of inventories of relief goods for different types of disasters, for example, heavy machines and equipments are needed to rescue trapped people under the rubbles in case of earthquake disaster while disaster-

pre evacuation of people to safer places is most needed help in the case of tropical cyclones and flood hazards, food and shelter are required for almost all of the disasters.

- proper land use planning for rehabilitation of evacuees
- emergency plans to tackle severe disasters
- suitable plans for evacuation and rehabilitation of oustees

The following aspects of disaster preparedness need further elaboration :

(1) level and nature of disaster preparedness
(2) disaster research
(3) disaster prediction
(4) disaster warning & communication
(5) diaster education

(1) Level and Nature of Disaster Preparedness

Various plans may be formulated and executed at different levels ranging from household preparedness to governmental preparedness as follows :

- household preparedness, each family should be mentally and materially (depending on the economic position of the family) should be in the state of preparedness in the event of a disaster.
- organizational preparedness including both public and private sectors, NGOs may play major roles in disaster management.
- inter-organizational preparedness, means full coordination between and among public and private organizations.
- community level preparedness, for example, there are different communities in the coastal zones such as fishermen community, business community, farmers community etc., each community requires disaster preparedness at varying levels, the fishermen should have the facility for early warning systems for tsunami occurrence, onslaught of tidal surges etc., the coastal zone communities should always be prepared to face the eventualities of disasters.
- governmental disaster preparedness includes the preparedness at the following levels :
  - (i) village level ('gaonsabha level'),
  - (ii) village 'panchayat' level,
  - (iii) development block level,
  - (iv) district level,
  - (v) state level, and
  - (vi) central government level.

(2) Disaster Research

Disaster research for the reduction and mitigation of natural hazards and disasters includes the following aspects :

- types and nature of hazards and disasters
- contributing factors of hazards and disasters
- mapping of disasters vulenerable areas
- prediction of hazards and disasters
- monitoring of natural hazards

Contributing factors : The types of natural hazards and disasters have already been described in the preceding section 17.2 of this chapter. The characteristics, severity and mode of occurrences of selected hazards and disasters will be discussed in the succeeding 18th and 19th chapters of this book. The contributing factors of hazard occurrences include the analysis of bedrocks and surficial geology, soils, water resources, land use etc.; atmospheric and ocean dynamics; precipitation and rainfall characteristics; stability and instability of hillslopes and hillslope failures; human activities which affect environmental processes (see chapter 15); human economic activities such as construction of dams and reservoirs, usbanization, land use changes (e.g. deforestation) etc.

Mapping of disaster vulnerable areas : The prime objective of disaster research is to gather information about different aspects of natural disasters such as topographical maps, aearial photographs, satellite images, past history of the area in terms of the occurrences (including frequency, magnitude, severity, recurrence interval of severe disasters), geographic information system (GIS), personal interviews, archives, governmental and non-governmental sources, experiments and rrsearches for preparing the maps of **'terrain risk areas' 'disaster vulnerability maps', 'major disaster zone maps'** etc.

GPS plays significant role in disaster mapping. Such types of disaster maps are of vital significance not only for disaster management but also for environmental planning, planners, administrators, NGO's etc.

The hazards and disasters maps are prepared on the basis of quantification of data related to different aspects of disasters such as magnitude, frequency, recurrent intervals of disasters of varying magnitudes and severity of disasters, quantum of damages done by disasters, terrain characteristics, accessibility etc. The disaster maps so prepared include different zones of varying intensities and dimensions.

Remote sensing techniques, aerospace surveys and GIS help in disaster management in the following manner :

- by providing detailed maps of the problem areas.
- by providing historic information gathered from local people to disaster researchers to better model the frequency and magnitude of hazards and disasters in an area.
- by providing a planning framework for local politicians, administrators and activists.
- by providing disaster reduction planning based on past experiences of disasters and awareness of disasters among the people.

Major disaster research programmes : mapping of natural hazards and global changes in environmental conditions are very important aspects of disaster management. This requires indepth study of hazard-prone areas at global, regional and local levels. The international Council of Scientific Union (ICSU) and other organizations have launched several research programmes to study the environmental changes caused by human activities and natural disasters in terms of mechanisms involved in the genesis of such disasters, their monitoring and mitigation. The following are the important programmes of disaster research and disaster mitigation.

SCOPE : The ICSU, an UN organization established a committee as the Scientific Committee on Problems of Environment (SCOPE) in 1969 to further enhance our standing of human influences on the environment and the events of environmental problems for governmental, intergovernmental and non-governmental organizations. The SCOPE also assists the United Nations Environment Programme (UNEP), Man and Biosphere Programme (MAB) of the UNESCO and World Climate Programme (WCP) of the WMO (World Meteorological Organization).

IGBP : The ICSU again launched an international research progamme to study global environmental issues in October, 1988 at Stockholm (Sweden) known as International Geosphere-Biosphere Programme (IGBP) or Global Change Programme (GCP). This programme stresses the study of interactive processes of physical environment such as terrestrial (lithosphere), marine and atmospheric components of the environment based on satellite remote sensing techniques, environmental monitoring and geographic information system (GIS).

HDGC : Social scientists have launched a parallel research programme named the Human Dimension of Global Change (HDGC). This programme is supported and funded by the UNO, the International Social Science Council (ISSC) and the International Federation of Institutes for Advanced Studies (IFIAS).

IDNDR : The United Nations Organization launched the International Decade for Natural Disaster Reduction (IDNDR) for the decade 1991-2000 A.D. to study the major natural disasters and to find out ways and means to alleviate their catastrophic effects on human society. The major objective of IDNDR was to reduce loss of life, property damage, and social and economic disruption caused by natural disasters through concerted international activities and cooperation. The disaster reduction programme under the purview of the IDNDR included only rapid processes such as earthquakes, volcanic eruptions, landslides, tsunamis, floods, windstorms, wildfires, locusts and droughts. Long-term disasters were not included in the immediate programme of the IDNDR. The following were the main goals of the disaster reduction programme under the framework of IDNDR :

- to improve the capacity of each country against natural disasters by the establishment of early warning systems,
- to foster science and technology aimed at closing critical gaps in the knowledge to reduce natural disasters,

- to disseminate existing and new information related to assessment, prediction, prevention and mitigation of natural disasters, and
- to develope measures for the assessment, prediction, and mitigation of natural disasters through various modalities and demonstrations.

(3) Disaster Prediction

Disaster prediction is a significant component of disaster management. The disaster prediction is made on the basis of the following :

- **past history** of the area, which is vulnerable to a particular hazard and disaster in terms of :
  - (i) disaster occurrence frequency,
  - (ii) recurrence intervals of major disasters,
  - (iii) magnitude and severity of disasters, and
  - (iv) dimension of disasters.
- **precursor events,** slow events which herald the occurrence of major events, for example, (1) there is surface creep of very slow rate of movement for longer duration before a major landslide occurs; (2) final violent eruption of a volcano is heralded by the bulging of ground surface, significant increase in local seismic activity, emission of volcanic gases, increase in the temperature of surface water or lake water present in the existing volcanic crater of old volcano, increase in the temperature of existing hot springs, geysers and fumaroles; deformation of the configuration of dormant or extinct volcanoes; significant changes in local gravity; (3) long-duration incessant high intensity rainfall is precursor event of probable flood; (4) regular occurrence of seismic tremors of minor to moderate intensities heralds the occurrence of major earthquake etc.
- **nature of causative factors,** for example, possible floods may be forecast on the basis of amount, intensity and duration of rainfall in the catchment area; spotting of tropical cyclones and local storms near their source areas and tracking of their paths of movement etc.

It may be pointed out that the prediction of rapid on-set disasters such as volcanic eruption, earthquake, tornado, landslides etc. either becomes difficult or deceptive. A few examples may be sufficient to validate this connotation :

- The prediction of major seismic events is almost impossible, because till date no effective mechanism of occurrence of earthquake could be evolved.
- The eruption of existing dormant and extinct volcanoes sometimes become easier to predict and sometimes eruption prediction becomes false and proves most disastrous; one example each for success and failure of prediction of volcanic eruption may validate the above statement.
  - (i) The eruption of Kilauea volcano in Hawaiiland, which occurred on 14th November, 1959 and again on January 13, 1960 was predicted well in advance and the prediction became true.
  - (ii) Professor Landes of St. Pierre College predicted on May 7, 1902 about non-occurrence of any eruption from Mt. Pelee located on the Martinique Island in the Caribbean Sea in near future but his prediction proved wrong on the following day as it was 8.02 a.m. of may 8, 1902 when gloom and dispair loomed large over the coastal town of St. Pierre as Mt. Pelee erupted with violent explosion and destroyed the whole of the town killing all the 28,000 inhabitants of the town leaving behind only two survivors to mourn the demise of their fellow persons.
- The occurrence and arrival of a few disasters is so quick and sudden that even they are predicted correctly but there is no sufficient time for evacuation and timely avoidance of onslaught of the disasters. The following two examples illustrate the limitations of disaster prediction :
  - (i) The unpredictability and ferocity of tornadoes make protection and prepar-

edness very difficult. Tornadoes are generally predicted on the basis of (a) detection and tracking of tornadoes by weather surveillance radar, and (b) prompt reports of visual sightings by competent observers. Recently, doppler raders are used in the study of different aspects of tornadoes and their prediction and warning. A doppler radar predicts the arrival of a tornado at a particular locality 20 minutes in advance but the time is so short that any step of preparedness proves ineffective, though people may go to safer places if tornado warning reaches them on time.

(ii) The tsunami meter predicts the arrival of tsunami at a particular coastal area 20 minutes in advance but again this time is not sufficient for safety of human and animal communities.

- The prediction of certain disasters, such as hurricanes, cyclones, typhoons etc. made on the basis of tracking of the storms by satellite radars and other prediction systems, is made well in advance but devastation of human health and wealth is not avoided. For example, two hurricanes viz. **Katrina** and **Wilma** struck the states of Louisiana and Florida, USA in 2005 and inflicted heavy loss of human lives and property, though all aspects of these disastrous hurricanes viz. their origin in the Caribbean sea, tracks of their movement, velocity and severity, were timely predicted. Hurricane Katrina almost flattened New Orleanse (August, 29, 2005) and left behind untold misery unheard in the hurricane history of this city. Hurricane Wilma, which hit Florida in October, 2005, was the strongest hurricane ever recorded.

Similarly, the supper cyclone of 1999 in Orissa, India, was correctly predicted and satellites tracked the cyclone and transmitted hourly pictures but the devastation of coastal districts of Orissa could not be avoided due to human failure.

- Floods in India are predicted on the basis of amount, intensity and duration of monsoon rainfall from June to September. S.W. monsoon is predicted on the basis of computer model by Indian Meteorological Department (IMD) which includes 16 parameters (see 'Climatology' by Savindra Singh, 2007, pp 428-429). Though the IMD predicted the onslaught of severe cyclones in the western India in the last week of July, 2005, but the unprecedented rainfall of 940 mm in 24 hours in Mumbai culminated into worst floods ever recorded in the history of the city, which claimed more than 1000 human lives. It may be mentioned that the city was not prepared and geared to face such disastrous situation.

(4) Disaster Warning Systems

Disaster warning system (DWS) comprises effective measures to communicate the human community of the area, which is liable to be hit by a particular disaster, about various aspects of a probable disaster. The DWS now a days uses advanced scientific knowledge and technologies of early warning system (EWS)which includes the following components :

- **trace indicators** having reliable mass data set regarding the nature, source of origin, speed, magnitude, severity, tracks and direction of movement (in the case of atmospheric storms, tsunami etc.), likely impacts, time of the hitting of the locality etc.
- **early warning tools,** such as radars, television, radio, news papers, hooters and sirens of alarm, door knocking, mobile loud speakers etc.
- **elements of warning systems;** detection of disaster, detectional warning, communication of disaster warning to concerned segments of society, response and quick review of disaster warning etc.
- **disaster warning centers,** local centers, regional centers, national centers, global centers (involving many countries, as is done in the case of tsunami occurrence in the Pacific Ocean).

- **mobilization of masses** for quick response to warnings and to follow the safety measures.

The success of disasters warning depends on reliability of warnings, proper functioning of electronic and print media of communication, sincerity of the agencies involved in the warnings, education and understandings of the general public, positive responses from the communities likely to be affected, accuracy of warnings, time factor etc. It may be mentioned that disaster warning is, in fact, the next step of disaster prediction because the predictions of various disasters have to be communicated to the people in time so that they may adopt necessary safety measures. Accurate and timely warnings may minimize damages to human lives and property. The disaster warning also depends on the nature and predictions of occurrences of disasters. Since the occurrence of seismic events cannot be predicted before hand, no warning can be issued in the case of an earthquake, but the tsunami can be predicted and hence warning can be communicated if the earthquake exceeding 7.5 on Richter scale occurs in the oceans.

The **'super cyclone'** of Orissa which struck Orissa coast on October 29, 1999 was well detected and predicted by satellite radars and was tracked since the formation of a depression on October 25, about 500 km east of Portblair in the Andman Sea (Indian Ocean), its further development and movement as a **deep depression,** and a **cyclonic storms** on October, 26, 350 km away from Portblair, **severe cyclonic storm** on October 27, 750 km away from Paradeep port in the Bay of Bengal, **super cyclonic storm** on October 28, near Paradeep with a velocity of 260 km per hour, and its final assault on October 29, 1999. Though hourly information and warnings were relayed by television and radio but due to the apathy of the state government and poor communication system the people could not be timely warned about the calamity which was looming large above their heads. Ultimately, the super cyclone entered Orissa on October 29, 1999 and began to play its game of destruction in 10 coastal districts. The supper cyclone resulted into the disruption of the supply of water and electricity. The communication system was thrown out of gear. Destruction and obstruction of roads and rails brought a grinding hault to rail and road transport which continued for weeks. Thousands of families suffered mental agony and pains due to separation of their kith and kins. According to official sources more than 10,000 people were killed and 200 villages were completely washed out but the unofficial sources put human death toll at about 100,000. The loss of property mounted to about 10,000 core rupees (1000 billion rupees).

The unfamiliarity with tsunami waves among the nations bordering Indian Ocean claimed more than 250,000 people in more than a dozen countries, mainly in Indonesia, Thailand, India and Sri Lanka. A powerful earthquake measuring 9.3 magnitude on Richter scale occurred at 00.58:53 (GMT), 7.58.53 (Indonesian Local Time) or 6.29 a.m. (Indian Standard Time) on December, 26, 2004 with its epicenter at Simeulue, off the west coast of Summtra in the Indian Ocean and generated powerful tsunami waves with a wavelength of 160 km and initial speed of 960 km/hour. Indian Meteorological Department (IMD) detected the occurrence of quake at 6.30 a.m. but could not think of the possibility of tsunami generation. Tsunami hit Car Nicobar at 7.50 a.m. but Indian scientists and government were unaware of the killer wave, though the air base officials at Nicobar informed Tambaram Air Force (Chennai) and the IAF chief informed the defence minister of India. The following tsunami diary tells the sad story of failure of Indian Govt. towards natural disaster management :

- The above mentioned quake struck at 6.29 a.m.
- Tsunami originated at 6.30 a.m.
- The IMD knew the quake at 6.40 a.m. but could not analyse data due to failure of computer.
- The Air Force Base at Nicobar informed Tambaram Air Force Station (Chennai) about Sumatra quake at 7.30 a.m. Indian Air Force chief informed the defence minister of India.
- Tsunami hit Car Nicobar at 7.50 a.m.
- Tsunami hit Tamil Nadu coast at 8.50 a.m.
- IMD informed (about the tsunami) to Crisis Management Group (CMG) at 8.31 a.m.
- Tsunami information was faxed to the secretaries of Science and Technology and Home Ministries at 8.56 a.m.
- Crisis Management Group met to assess the extent of damage and to discuss rescue and relief work in the afternoon of December, 26, 2004.

It appears from the above chain of events that the information about tsunami hitting India crawled at snail space and took two hours time to reach the government officials. The scientists and administrators were ignorant about even the name of tsunami as is apparent from the following statements :

"It was beyond our horizon of imagination"

—Union Minister for Science and Technology"

"Till 8.30 a.m. we were clueless"

—Secretary, Science and Technology Ministry

"Tsunami don't happen in India"

— Director of Seismology, IMD

(these three statements have been quoted from Down to Earth, January, 31, 2005).

It may be mentioned that there is network of **Pacific Tsunami Warning System** (PTWS) comprising 26 member ocean countries that face the fury of tsunami waves very frequently. "Had any of the Indian Ocean nations (except Indonesia) been member of the PTWS, they would have got the advisory and India would have had at least three hours before the tsunami actually struck its coast, to order evacuation or signal people to move to safety" (India Today, January, 10, 2005).

It may be noted that the PTWs based at Hawaii center released the news of Sumatra Tsunami on its website and warned two subscriber nations Australia and Indonesia about impending danger of tsunami but did not pass on the information to India and Sri Lanka because firstly they were not the members of PTWS and secondly the phone numbers of concerned officials were not known.

It may be concluded that it is not the prediction and early warning of natural disaster which can save human life and property alone, but human dimension is also equally important. If the persons concerned with disaster prediction and warning do not work with sincerity and integrity, if the warning of impending disaster does not reach the people well in advance, no science and technology can be effective in disaster management.

(5) Disaster Education

The prime goal of disaster education is to educate the people about various aspects of hazards and disasters, such as nature and mode of occurrences, magnitude and severity, nature and magnitude of damage, prediction and warning system of disaster, preparedness and safety measures, adjustment with disaster etc., so that they are least adversely affected by disasters of various sorts. In fact, education on disasters plays an important role in various programmes of disaster reduction and management. Disaster education must be broad-based and must reach everyone including scientists, engineers, policy and decision makers and general public through popular media such as news papers, radio and television broadcasts, documentary films, poster displays, seminars and workshops, 'nukkar natak' (street corner drama), popular slogans, booklets, handouts, child and adult education etc. In most of the countries the responsibility to educate and inform the public about the impending hazards and disasters lies with governments and thus researchers and scientists must educate the decision makers (administrators and politicians) about disasters reduction and management. It may be remembered that a British school girl, who was taught about tsunami in her higher secondary school, saved her family members and a few more people from being swallowed by furious tsunami waves on Phuket Island of Thailand, generated by December 26, 2004, Sumatra quake. Disaster education aims at the following :

- to arouse perception and awareness about hazards and disasters among decision and policy makers and general public and to train the decision makers to handle the situation created by a disaster.
- to provide information about possible disaster well in advance.
- to provide disaster risk and vulnerability maps.
- to persuade the people to improve the standard of constructions so as to escape the disasters.
- to acquaint the people about safety measures in the event of occurrence of a disaster.
- to explain the disaster reduction techniques.
- to motivate the local people for rescue operation and relief work.
- to persuade people to change their age-old attitudes and perceptions towards natural hazards and disasters.
- to persuade people to adopt proper scientific techniques and safety measures to minimize damage of various sorts.

2. DISASTER MITIGATION

While disaster preparedness includes all those measures which enable the people to cope with the adverse situations created by disasters, disaster mitigation focuses on the following two major objectives :

(1) to minimize the disruptive forces of disasters, and to reduce the magnitude of disasters.

(2) to lessen the adverse impacts of disasters.

It may be mentioned that the primary goal of disaster preparedness is to save human lives from disasters but disaster mitigation also aims at reducing economic losses in case of disaster occurrences. So disaster mitigation lays more emphasis on economic impacts of disasters. The nature of disaster mitigation depends on the nature of disaster and environmental conditions of the area which is vulnerable to a particular disaster. For example, terrain characteristics, human structures (buildings and building materials, density of settlements etc.), population density etc. may be of vital consideration for earthquake disasters while human population & settlements, coastal configuration, ecological setup etc. of coastal zone may be more significant for cyclonic storms, tidal surges and tsunamis in the coastal areas. The terrain characteristics are very important factors for the flood disasters created by meandering alluvial rivers.

The following measures, which are also integral parts of disaster preparedness, are prerequisite conditions to minimise adverse impacts of natural disasters mainly economic and property losses :

- Mapping of disaster-prone areas and preparation of disaster zones maps.
- Proper land use planning and prohibition of such land uses which may accentuate disasters. For example, coral mining, sand mining from sea beaches, reclamation of coastal lowland areas and swamps for development purposes, destruction of mangroves etc. accelerate the disruptive forces of disasters. In fact, these are frontline natural buffer zones which protect the coastal lands from the onslaught of tidal surges and tsunamis.
- Provision of coastal protection through constructing sea walls and planting mangroves.
- Improving structures and following of disaster-safe building designs and codes. It may be mentioned that it is not the earthquake that kills people, rather it is the buildings which kill people.

The following are two basic approaches to meet out the disaster mitigation programmes.

(1) top-down disaster mitigation approach

(2) bottom-up disaster mitigation approach

The **top-down approach** of disaster mitigation entirely depends on different measures of disaster management initiated by the government establishments at different hierarchical orders such as at national, state, tahsil, block levels etc. There are many beaurocratic hurdles and complications at government levels in implementing disaster mitigation programmes and hence actual victims of disaster-hit areas do not get the benefit of disaster mitigation measures. Some times there is absence of such scheme in many countries. The example of Hurricane Katrina which flattened and devastated New Orleans city of the USA in 2005 tells the story of government apathy towards saving the lives and property of the victims. The alternative disaster mitigation approach is **community-based bottom-up approach** wherein there is direct involvement of local people who participate in disaster mitigation mission. The community participation involves from local community to world community as follows :

- local community level participation
- non-governmental organization (NGOs)
- gram panchayat and block-level participation
- state-level participation
- central government level participation
- world community level participation

It may be mentioned that any disaster mitigation measure cannot be successful unless sufficient monetary fund and ample infrastructure are made available but this cannot be possible at local community level as fund and infrastructural facilities and other resources are limited and hence sufficient funds must come from 'central cell' and 'state government cell'. What is required is to motivate local community to actively participate in disaster mitigation programmes. The necessity of community participation may be justified by the following two examples :

(i) The total lack of community participation at the time of Katrina calamity in the city of New Orleans (USA) in 2005 exposed the weakness of materialistic society of the highly industrialized western world as the absolute lack of social bond and sense of belonging allowed the anti-social elements to exploit the victims of Katrina disaster at the most critical time of distress. Not only the anti-social elements indulged in all sorts of malpractices but also tried to stop the relief team to enter the storm-hit city. Many of them fired at the helicopters having relief items and experts hovering over New Orleanse city.

(ii) The example of flood deluge of the city of Mumbai due to unprecedented and incessant high intensity rainfall amounting to more than 900 mm (940 mm) within 24 hours on July 26, 2005, illustrates the high social bond and strong community feeling in rescuing the flood marooned people and saving hundreds to thousands of human lives. Not even a single case of malpractice (rape or robbery) was reported.

It may be summarized that **government based mitigation** (GBM) should be associated with **community based mitigation** (CBM) so that the benefits of disaster mitigation measures reach the victims.

There are certain constraints which hinder the implementation of disaster mitigation programmes such as governmental constraints (lack of proper resources, lack of provision for regular involvement of government at different levels in disaster mitigation, lack of proper legislation etc.); social constraints; political constraints; legal implications; financial constraints (lack of budgetary provision for disaster mitigation fund, poverty and technological backwardness etc.) etc.

3. DISASTER PREVENTION

It may be mentioned at the very outset that disaster prevention does not mean to prevent the occurrences of natural disasters rather it means to prevent the adverse impacts of natural disasters by adopting certain measures much in advance of the occurrence of a disaster. It is, thus, evident that disaster prevention is based on the outcome of disaster preparedness and disaster mitigation as discussed earlier. Disaster prevention includes all those activities which help in preventing the harmful effects of natural disasters on human lives and property. It may be mentioned that there are some natural safeguards against natural hazards and disasters. For example, coral reefs, beaches, mangroves, coastal wetlands (swamps, marshes and backwaters), coastal sand dunes etc. which act as **natural** or **frontline buffers** and absorb most of the energy of disruptive forces of natural hazards and save the coastal zone and its inhabitants from the devastation caused by natural oceanic disasters such as cyclonic storms and tidal surges, tsunamis etc.

Mangroves are the most significant natural buffers against oceanic disasters. According to the studies conducted by US-based Earth Institute, previously mangrove forests covered about 75 per cent of the coastlines in the tropical and subtropcal regions but now (upto 2005 A.D.) only 50 per cent of coastlines have mangrove forests. There are still some patches of rich mangroves along the east coasts of India. The Sunderbans in West Bengal and Bhitarkanika in Orissa are the largest and second largest mangrove forests. It was the mangrove forests at Bhitarkanika which saved the locality from the ferosity of 1999 super cyclone of Orissa. The Pichavaram and Muthupet having dense mangrove forests in Tamil Nadu coast absorbed the tsunami force on December 26, 2004 (Sumatra tsunami) and minimized the casualties and property damage while Nagapattinam and Cuddalore suffered heavy loss of human life and property. Destruction of mangroves, reclamation of coastal lowlands and wetlands, coral mining, sand mining from beaches, destruction of coastal sand dunes for various developmental projects have led the east coasts of India most vulnerable to oceanic hazards and disasters. Inspite of large areal extent and fairly larger area of high ground the Indian east coasts mainly in Tamil Nadu suffered most from tsunami impact in 2004 due to destruction of **natural life line** comprised of mangroves, sand dunes, beaches and coral reefs while Maldives comprising tiny 1190 islands in the Indian Ocean and on an average emerging hardly one meter above sea level, having no high ground that can provide safe refuge at the time of oceanic disasters, was least impacted by December 26, 2004 tsunami because rich coral reefs encircling tiny islands absorbed most of the energy of tsunami force and restricted human casualties to only 85 deaths.

Stability of hillslopes covered with dense forests prevents massive landslides but massive deforestation world over has exposed many hillslopes and has made them more vulnerable to frequent landslides. It may be mentioned that dense forests also act as natural buffers against landslides. Construction of roads and buildings has also destabilized hillslopes and has accelerated the process of landslides. Avoidance of steep hillslopes for road and building construction, farming and horticulture; reforestation and afforestation may be effective preventive measures for accelerated soil erosion and landslides.

The water-logging in the urban areas resulting from high intensity incessant rainfall of long duration is not always primary cause of urban flood but at times it becomes the result of human failure. For example, the Mumbai deluge of July 26, 2005 was not only because of 940 mm of rainfall within 24 hours but it was also because of choking of outlets of accumulated water and lack of proper drainage which may allow quick disposal of rainwater. It is, therefore, imperative that the urban authorities should make provision for proper drainage and quick disposal of rainwater in the event of incessant heavy rainfall. The riverine cities should also be well protected from flood waters of the rivers entering the cities by the construction of riparian dykes of various sorts. The following measures should be adopted to minimise the devastation by severe floods of the rivers :

- to delay the return of runoff resulting from torrential rainfall to the rivers,
- to hasten the discharge of rivers,
- to reduce the volume of water,
- to divert the flow of river water,
- to reduce the impacts of floods,
- to forewarn the occurrence of floods, etc.

These aspects have been discussed in detail in the 19th chapter of this book.

The following are the preventive measures of earthquake disasters :

- to avoid the earthquake-prone areas for human settlements,
- to use standard building materials for constructing different types of buildings,
- to follow earthquake-resistant standard designs for the construction of buildings,
- to restrict the construction of high rise buildings in the quake vulnerable areas,
- to prepare earthquake risk zone maps,
- to adopt safety measures, etc.

Very high human casualties and heavy loss of property in the case of recent Muzaffarabad quake (POK) on October 8, 2005, which measured only 6.5 on Richter scale, were caused not because of the magnitude of the quake, rather were caused due to negligence of all the preventive measures, as referred to above, of earthquake disasters. The same mistakes resulted into heavy loss of human lives and property (more than 6200 people died, more than 46,000 people were inured of which 33,000 suffered from serious injuries, more than 139,000 homes were destroyed) when a moderate earthquake measuring only 6.3 on Richter scale rocked Central Java on May 27, 2006, epicenter being at Yogyakarta, 400 km east of Jakarta, the capital of Indonesia.

POST-DISASTER STAGE

Post-disaster phase of disaster management reflects the resilience of disaster affected communities towards facing the calamities introduced by a particular or a host of disasters. The post-disaster stage comprises the following steps to absorb the adverseries of natural disasters :

(1) relief measures,

(2) recovery from shocks of disasters, and

(3) rehabilitation of displaced communities.

(1) Relief Measures

The moment a disaster occurs in an area, the immediate steps to be taken are to rescue people buried under debris, to provide food, drinking water, shelter, medicines, to restore power and water supplies and communication and trasnsport systems. The following are the significant components of relief measures at the time of occurrence of a disaster :

- social response and action,
- participants in relief work,

- organizational involvement,
- correct picture of nature, magnitude and severity of disasters and necessary requirements,
- priority fixation of relief measures,
- zonation of priority on the basis of magnitude of damages and requirements, and
- active participation in relief work.

Social Response : There is instantaneous response in humans to help each other during the time of disasters cutting across political, religious, ethnic, territorial and physical boundaries because the human stinct is stirred up by the news, pictures or on the spot scenes of misery of nature's anger.

The social response to disasters is largely determined by the communications of mediamen like news paper reporters, television news, gossips etc. Thus communications are of crucial importance in the assessment and reduction of disasters. Generally, the opinion makers and media people report about the disasters based on their own assessment having limited observations. If their reports are based on misconceptions the problems arising out of a particular disaster are further complicated because the nature of social response to the disaster is guided by the nature of reports. It is important to note that 'It is man and his response to disaster that is at the heart of disaster management... Man is a product of his social as well as of his physical environment, and it is in times of disaster that these strong bonds with his origins manifest themselves and take precedence over his ordinary behaviour. It is then that he realizes his dependence on kin and neighbour, his roots in the soil where he grew up, and deep meaning of home that shelters him. In time of crisis, he may suddenly realize that these are as much part of him as his limb, and that losing any of these is deeply damaging' (K. Nimpuno, in Aerospace Survey and Natural Disaster Reduction, ITC Enschede, Netherlands, 1989).

It is heartening to note that social response to disasters is increasing positively and immediate relief measures are forthcoming from within the country(where disaster has occurred) and from out side the country. Several nations and voluntary social organizations involve themselves immediately in providing relief measures and helping and serving the disaster victims. Since the relief measures in terms of kind such as food, clothes, medicines etc. and men such as volunteers, doctors, nurses, engineers etc. are immediately arranged and sent on the basis of reports of news media and not on the basis of specific requests of the disaster-affected nation, such hasty steps create certain problems instead of mitigating the calamity. The emotional strong social response to the earthquake disasters in **Mexico city, Mexico** (1985), Armenia (1988), northern Iran (1990), December 26, 2004 tsunami disaster triggered by undersea Sumatra quake (9.3 on Richter scale) in the Indian Ocean, October 8, 2005 quake of Muzaffarabad (POK), May 27, 2006 quake of Java etc. reveals the instantaneous urge of humans to help their fellow men in distress. The example of relief measures arranged by human communities for the victims of earthquake disaster in Mexico city during 1985 clearly demonstrates the nature of social response to disasters.

The damage done by the devastating earthquake included death of 5000 people, disappearance of 2000 people, injuries to 40,000 people, destruction of 400 buildings, damage to 6000 buildings, lesser damage to 50,000 buildings. Besides, infrastructure of the city such as water pipes, power supplies, tele-communication systems, transport systems etc. was seriously damaged. The social response from within the city was quick and impressive. Children took over the charge of traffic control at road crossings and thus relieved traffic police to take up rescue operation. Social workers and volunteers poured in from various parts of the country and within hours more than 50,000 odd volunteers pressed themselves in the salvage work and worked tirelessly for several days and brought out several buried people alive even after a week later. The following description by K. Nimpuno (1989, in Aerospace Survey and Natural Disaster Reduction, ITC, Enschede, Netherlands) reveals the magnitude of problems created by unsolicited relief measures in disaster affected areas :

"The disaster brought massive assistance from abroad, most of it unsolicited, much of it unwanted. Much of the goods and personnel that landed in Mexico reflected the expectations of the relief agencies and not the needs in Mexico city. Within days, more than 1000 tons of materials arrived. Tons of medicines arrived and caused handling and storage difficulties. Medical teams, a planeload of Dutch medical staff among them, appeared from all over the world, but they were unneeded and unwanted. Without local knowledge, not speaking the language, they needed accommodation, transport and interpreters and thus added to the confusion."

"Despite all the damage, Mexico city had more than enough medical resources : 20,400 physicians, 32,800 nurses, 500 ambulances, 110 hospitals and 844 clinics. The foreign medical team had no role to fulfill. Some started vaccination campaigns without being asked and reinforced unfounded fears of epidemics" (K. Nimpuno, 1989).

It does not mean that foreign relief measures are always useless. Such measures become more effective when they conform with the need of the affected people and demanded by the government of that country. For example, the Mexican government did make requests for certain items such as special rescue tools, communication equipments, some medical specialists and heavy machines to remove the debris of collapsed buildings and these items were supplied by developed countries.

It may also be pointed out that there are some anti-social elements as well who resort to looting, robberies and rape during disasters not only in developing countries but also in some cases in developed countries. The cases of looting and raping were reported in the Virgin Islands of the USA after the deluge of Hugo hurricane was over. The US govt. had to fly troops in Virgin Islands to protect the hurricane victims and other citizens from anti-social elements.

A few anti-social elements were involved in taking undue advantage of Katrina hurricane disaster which occurred in 2005 and devastated the city of New Orleans, USA, as they resorted to malpractices of looting the property and raping the already troubled women. Even they fired at the helicopters carrying rescue team.

Participation in Relief Work : It has already been pointed out that relief measures at the time of major disasters require huge amount of money and materials and heavy equipments for rescue operation and they cannot be possible without government assistance and international cooperations but the execution of relief work may be made effective by taking the help of local people and voluntary organizations. The following are the participants in the operation of relief work :

- individuals
- community
- social groups
- non-government organizations (NGOs)
- government organizations
- international participation

  such as UN Red Cross Crescent Societies, League of Red Cross, World Health Organization, International Council of Voluntary Agencies, UNDRO etc.

Relief Materials : The relief materials include rescue team and necessary equipments for rescue operation, monetary fund, relief commodities as follows :

(1) **rescue team :** comprising expert team, technicians, heavy equipments in order to rescue the victims buried under rubbles etc.

(2) **medical team :** comprising doctors, nurses, volunteers if demanded by the disaster-hit country.

(3) **relief materials** : comprise food items, safe drinking water, tents, generators, communication devices, lighting items, medical equipments, cooking gas cylinders and stoves, wood, coal, blankets, garments etc.

(4) **monetary fund :** received from individuals, institutions, voluntary social organizations, as donations; government agencies as financial help; and from international communities.

Execution of Relief-Work : The supply and distribution of relief materials should be accomplished with the help of local communities and voluntary social organizations under the umbrella of government officials. The execution of relief measures for disaster victims involves the following steps :

➤ There should be **correct picture** of the nature, magnitude and severity of disasters. Very often the news media (both print and electronic media) report their own versions based on misconceptions and rumours instead of reporting the real events. This is not done deliberately. The misconceptions about a particular natural event arise because of the personal views of the media observers and analysers. It is, therefore, desirable for the international communities to respond to the official requests of the concerned government only. It may be remembered that many countries including the USA offered help in the form of money and kinds to Indian Government at the time of December 26, 2004 tsunami tragedy but the Govt. of India refused to accept the help as many countries bordering Indian Ocean were more seriously damaged in terms of human lives and property (such as Indonesia, Thailand, and Sri Lanka) and hence they needed help first. Instead of accepting foreign assistance India rushed relief materials and rescue teams to Maldives, Sri Lanka, Indonesia etc. and thus acted as a responsible senior friend.

- **Priority** must be decided before undertaking the remedial and relief measures. For example, relief measures must be concentrated in the high density areas of the affected locality. The disaster-affected area should be divided into different zones on the basis of magnitude of devastation and relief work should be done according to priority zones. The following sequence of priority should be adopted :
  - (i) Rescue operation should be initiated first. Rescue team must be equipped with specialized experts in rescue operation, necessary equipments and machinery, volunteers, sniffer dogs, electronic devices etc. to locate and extricate disaster victims trapped in the debris, to treat them with first aids, to transport them to nearby hospitals, if needed, or temporary shelter houses.
  - (ii) There should be proper listing of dead and injured, and missing people and the information should be communicated to general public.
  - (iii) The injured victims should be given proper medical help.
  - (iv) Proper supply of food and drinking water.
  - (v) Restoration of water and electricity supplies.
  - (vi) Restoration of transport and communication systems.
- Relief measures should be provided by foreign countries only after they are requested by the disaster-affected country or the offers of relief materials from other countries are accepted by the concerned country because unofficial, unwanted and unsolicited relief supplies of men and materials create confusion and complicate the problems created by a particular disastrous event instead of solving them. Many of the countries after hearing the disaster from electronic and print media immediately dispatch huge consignments of medicines and doctors which are no longer needed so much. Thus huge amount of money is wasted on medicines, which otherwise is more needed in other assistance areas.

(2) Disaster Recovery

The recovery from adverse effects of a disaster begins from an individual to a community. Question arises, recovery of what? recovery from where?, recovery of whom?, and many more. In fact, recovery is a process that involves adaptation and adjustment of disaster victims to new conditions created by a particular disaster. In other words, recovery process includes all those actions and activities which help the individuals and communities to adjust with the effects of all sorts left behind by a particular disaster. Thus, recovery process involves multiple strategies to get rid off the adverse effects of disasters. The adversaries of a severe disaster may include physical and mental injuries, loss of property, separation of family members, mental agony of social evils committed by anti-social elements, loss of territory, loss of native culture etc.

Since disaster recovery is a community-based process, community participation is a prerequisite condition to recover the individuals and the community from the agony of the trauma of disasters. The first and foremost step in disaster recovery process is to rebuild the confidence level of disaster victims by bringing them in the mainstream of community programme, by injecting a sense of belonging and brotherhood, by making them active in the recovery process so that they may forget the fear psychosis created by the disaster, by diverting their mind from the sad memory of the destruction caused by the disaster through recreation (by showing comedy and family friendly movies, documentary films), leisures, community education, 'pranayam and yoga', spiritual teaching, participation in community development programmes etc. This process may be called **mental recovery. Economic recovery** may be effected by grantnig liberal monetary fund for rebuilding dilapilated houses and repairing partially damaged houses, for purchasing and maintaining infrastructural facilities to earn livelihood, for giving education to children etc. **Social recovery** involves adjustment of community to new conditions created by a disaster through following measures :

- change in the attitudes and perceptions of individuals and community and institutions towards natural disastrs.
- community education through electronic and print media, personal contacts, group discussions, documentary films etc.
- involvement in community development programmes.
- continuous flow of information regarding all the steps taken for recovery and rehabilitation programmes.
- rehabilitation of and healing touch to the victims of anti-social elements, to rebuild self confidence and to bring them in the mainstream of community life.

(3) Rehabilitation

It may be mentioned that recovery and rehabilitation are time consuming lengthy and costly processes as these require long time and huge amount of money for successful execution of recovery and rehabilitation programmes as rehabilitation process involves **renewal** of disrupted systems, **repair** of damaged systems and **reconstruction** of houses, buildings, roads, rails, bridges and other items of utilities, **relief employment** etc. The success of rehabilitation of distressed and displaced people depends upon the economic health of the concerned country. It may be mentioned that the victim country, what so ever big, strong and rich it may be cannot manage all the segments of disaster reduction and management programme on its own resources. It may be remembered that the USA, superpower, had to ask for help from world communities when deadly hurricane Katrina ravaged the city of New Orleans in 2005. Similarly, the relief, recovery and rehabilitation cannot be successful on local resources alone. Thus, monetary, administrative and technological assistance from government departments and even international communities becomes necessary for natural disaster reduction. The following two tables (17.2 and 17.3) may give the clear picture of the extent of devastation caused by December 26, 2004 tsunami in India and the quantum of financial requirement for the rebuilding and rehabilitation programmes :

Table 17.2 : Dimension of December 26, 2004 tsunami devastation in India

	Tamil Nadu	Kerala	Andhra Pradesh	Pondichery	Andman & Nicobar	Total
Population affected (in lakhs)	8.97	13	1.96	0.43	356	27.92
Number of villages affected	376	187	301	33	192	1089
Actual deaths (excluding missing persons)	8009	117	107	599	3513	12405
Houses damaged	1,90,000	13,735	481	10,061	21,100	2,35,377

Cropped area affected (hectares)	19,168	7,763	302	792	11,010	39,035
Boats damaged	52,638	10,882	12,189	6,678	1,401	83,788
Livestock lost	1,653	0	86	2,685	27,331	31,755
Damage (in crore rupees)	4,528.66	2,371.02	342.67	466	3,856.56	11,544.91

Source : "Tsunami—A Report to the Nation" published by the Ministry of Information and Broadcasting, Govt. of India, in Hindu, December 26, 2005.

Table 17.3 : Rehabilitation package for December, 26, 2004 tsunami devastation, India, under Rajiv Gandhi Rehabilitation Programme (Rs. in crores)

Items	Tamil Nadu	Kerala	Andhra Pradesh	Pondichery	Andman & Nicobar	Total
Relief and response	233.22	17.16	8.12	26.03	107.35	391.99
Sustenance allowance	118.80	12.30	00	1.05	23.04	155.19
Temporary shelters	90.00	17.39	0.31	6.04	99.10	212.84
Permanent housing	650.00	50.00	2.30	50.00	00.00	752.30
Relief employment	54.00	26.00	12.60	1.95	9.75	104.30
Infrastructure	161.15	44.01	10.35	6.61	305.97	528.09
Agriculture and animal husbandry	32.35	3.52	1.16	0.80	261.66	249.49
Assistance to fishermen	1007.56	78.98	35.16	63.14	15.01	1199.85
Total	2347.19	249.36	70.00	155.62	821.88	3644.05

Source "Tsunami—Report to Nation", published by the Ministry of Information and Broadcasting, Govt. of India, in Hindu, December 26, 2005.

It is apparent from tables 17.2 and 17.3 that the quantum of damage (Rs. 11544.91 crores) done by December 26, tsunami in India far exceeded the amount spent on rehabilitation and relief programmes (Rs. 3644.05 crores).

It may be summarized that recovery and rehabilitation processes are most significant aspects of post-disaster phase of natural disaster reduction and management which needs assistance from individuals to communities, concerned nation and international communities. The success of recovery and rehabilitation processes depends on political systems, nation's readiness for any contingency plan, community participation, financial position, organizational structures of post-disasters activities e.g. relief work, recovery and rehabilitation, social structure, fixation of priorities for rehabilitation, role of voluntary organizations (NGOs), formation of accurate plans for rehabilitation, cooperation of local people, administrative assistance, resilience of the community etc.

18

TERRESTRIAL HAZARDS AND DISASTERS

Terrestrial hazards normally include those extreme tectonic events which are caused by endogenetic forces coming from within the earth. In fact, the causative factors of terrestrial extreme events and hazards are hidden deep within the earth and are not observable by man. Only their effects are experienced, rather badly, by human beings. Such extreme events include earthquakes, tsunamis, volcanic eruptions, major natural landslides, avalanches etc. Most of the terrestrial natural extreme events are caused by tectonic movements of the lithospheric and oceanic plates relative to each other caused by thermal conditions of the interior of the earth. Those volcanic eruptions become more hazardous and disastrous which occur after long period of dormant phase. The examples of sudden eruption of dormant volcano of Mt. Helgafell in January, 1973, on the island of Heimaey (with 5000 people), Iceland and Mt. Pelee eruption on May 8, 1902 (28,000 deaths) are sufficient enough to tell the sad story of destructive and disastrous hazards which virtually buried the town of Vestmannaeyjar in ash and lava flows and St. Pierre city was completely destroyed by burning lavas killing 28,000 people. The recent severe earthquakes of Darbhanga in Bihar (India, 1988), Bhuj (India, 2001), Armenia (1989), Muzaffarabad in Pakistan occupied Kashmair (POK) (2005) and of Java (2006) are the examples of severe natural hazards and disasters which inflicted great damage on human lives and property.

The killer tsunami generated by powerful under sea earthquake off the coast of Sumatra on December, 26, 2004, in the Indian Ocean claiming more than 250,000 lives in the countries bordering Indian Ocean mainly Indonesia, Thailand, India and Sri Lanka is another example of severe disaster caused by endogenetic forces.

18.1 TYPES OF TERRESTRIAL DISASTERS

Terrestrial hazards and disasters belong to the category of **rapid-onset disasters** which occur all of sudden, though there is relatively long period-preparatory stage inside the earth but we do not know about such hidden geological happenings. As stated above, terrestrial hazards and disasters are caused by endogenetic forces and hence these are called **endogenous hazards and disasters.** The following four types of terrestrial hazards and disasters are identified :

1. Volcanic disaster,
2. Seismic disaster,
3. Tsunami disaster, and
4. Landslide disaster.

18.2 VOLCANIC DISASTER

Volcanic hazards and disasters are associated with volcanic eruptions of both types e.g. violent central eruptions and fissure lava flows. The volcanic hazards include lava flows and **'lahar'**, mud flows, eruption of dusts, ashes and fragmental materials, toxic gases, smokes and soots etc.

Volcanic eruption is another example of natural terrestrial hazard but unlike earthquakes, volcanoes are both hazards/disasters and boons to human beings because they destroy human settlements, agricultural farms, and kill people and animals and destroy human properties through explosive central eruption and spread of hot and liquid lavas coming out of fissure flows as well as they provide rich soils for agricultural purposes.

More or less there is well marked distributional pattern of volcanoes over the globe. On the basis of nature of eruption volcanoes are divided into two broad categories viz. (1) **Explosive type** of volcanoes wherein volcanic eruption occurs through a central pipe by breaking and blowing of crustal surface due to violent and explosive gases accumulated deep within the earth. Such volcanoes are very destructive. Explosive volcanoes are further divided into 5 sub-types viz. (i) **Hawain type** of volcanoes, (ii) **Strombolian type** of volcanoes, (iii) **Vulcanian type** of volcanoes, (iv) **Pelean type** of volcanoes, and (v) **Visuvius type** of volcanoes. This subdivision is based on the intensity of eruptions of volcanoes and typical cases of specific eruptions. (2) **Fissure eruption** type of volcanoes. Such volcanoes occur along a long fracture, fault and fissure and there is slow upwelling of magma from below and the resultant lavas spread over the ground surface. The speed of lava movement depends on the nature of magma, volume of magma, slope of ground surface and temperature conditions.

Distribution of Volcanoes

Like earthquakes, the spatial distribution of volcanoes over the globe is well marked and well understood because volcanoes are found in a well difined belt or zone. Thus the distributional pattern of volcanoes is zonal in character. Like earthquake belts, there are also three major belts/zones of volcances (fig. 18.1) as follows :

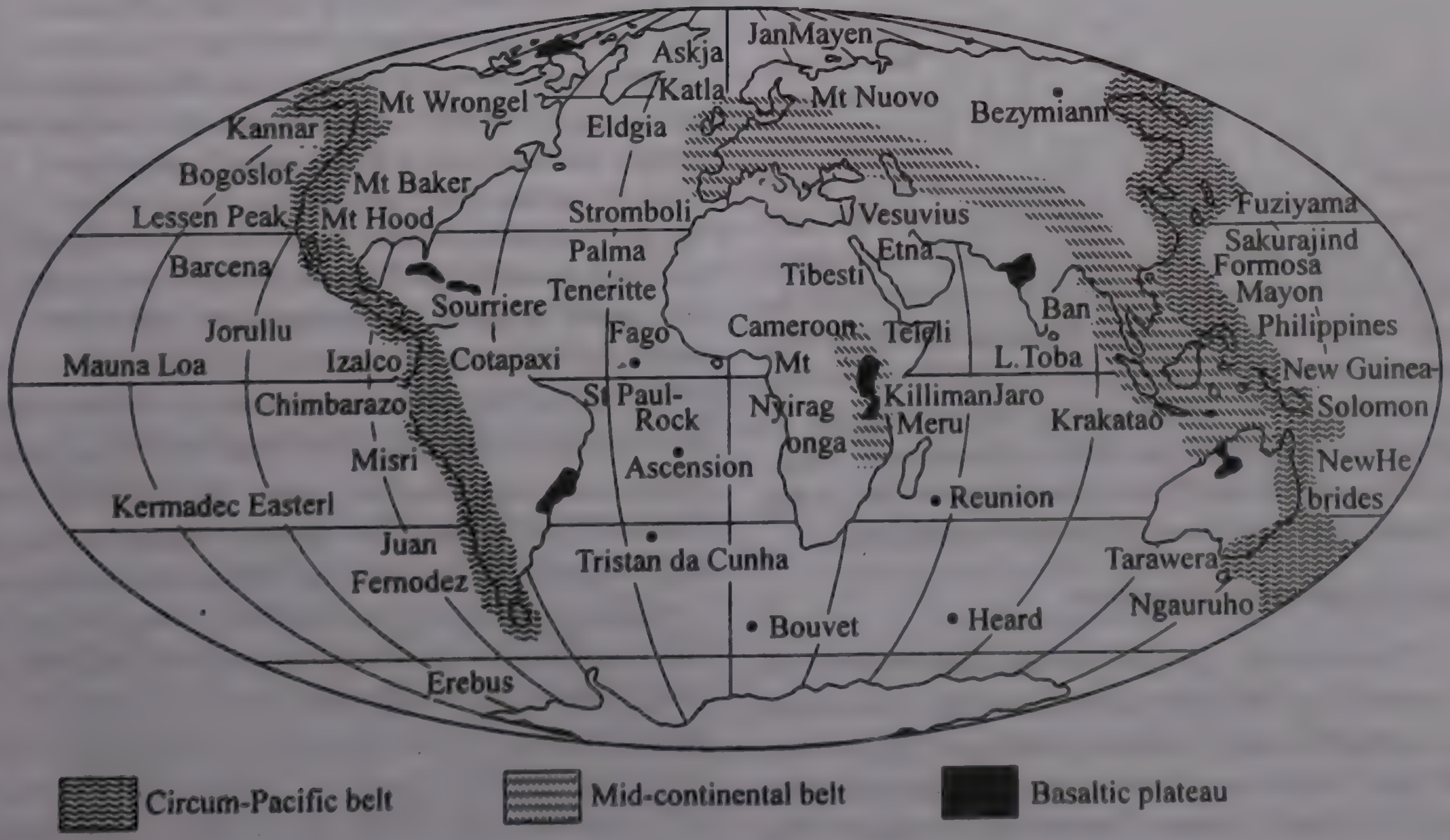

Askja
JanMayen
Katla
Mt Nuovo
Bezymiann
Mt Wrongel
Kannar
Eldgia
Bogoslof
Mt Baker
Lessen Peak
Mt Hood
Stromboli
Vesuvius
Fuziyama
Sakurajind
Formosa
Mayon
Barcena
Palma
Etna
Tibesti
Sourriere
Teneritte
Ban
Philippines
Jorullu
Fago
Cameroon
Teldli
Mauna Loa
Izalco
Cotapaxi
Mt
L.Toba
New Guinea
St Paul-Rock
Chimbarazo
Nyirag onga
KillimanJaro
Meru
Krakatao
Solomon
Misri
Ascension
NewHebrides
Kermadec Easterl
Reunion
Juan Fernodez
Tristan da Cunha
Tarawera
Ngauruho
Bouvet
Heard
Erebus
▨ Circum-Pacific belt
▤ Mid-continental belt
■ Basaltic plateau

Fig. 18.1 : World distribution of volcanoes.

(1) Circum-Pacific belt or Pacific ring of fire,

(2) Mid-continental belt, and

(3) Mid-oceanic ridge belt.

Circum-Pacific belt and mid-continental belt account for a bout 80 per cent of the total active volcanoes of the world. It may be pointed out that there is very close relationship between the plate boundaries and volcanic belts. In fact, more than 80 per cent of the world's active volcanoes are found along the destructive or convergent plate margins (boundaries). The Circum-Pacific belt includes the volcanoes of the coastal areas of the Pacific Ocean (both eastern and western) or say the coastal margins of North and South Americas (representing eastern coastal areas of the Pacific) and eastern coastal margins of Asia (representing western coastal areas of the Pacific), of island arcs and festoons and of oceanic islands. This volcanic belt is also called as the **'fire girdle of the Pacific Ocean'.** Here volcanoes are primarily caused due to collision of convergent plates along the Benioff zones. Mid-continental belt includes the volcanoes of Alpine mountain chains and the Mediterranean Sea and the volcanoes of fault zone of eastern Africa. This belt also represents the destructive or convergent plate margins (boundaries) or say the collision zones of Eurasian plate and the African and Indian plates. The famous volcanoes of the Mediterranean Sea such as Stromboli, Visuvius, Etna and volcanoes of Aegean Sea are included in this belt. This belt does not have the continuity of volcanic eruption as several gaps (volcanic-free areas) are found along the Alps and the Himalayas because of compact and thick crust formed due to intense folding activity. The Mid-oceanic ridge belt includes volcanoes mainly along the mid-Atlantic ridge which represents the splitting zone of plates. In other words, plates diverge in opposite directions from the mid-oceanic ridge. Thus volcanoes mainly of fissure type occur along the constructive or divergent plate boundaries.

Causes of Volcanic Eruptions

If we look at the world distribution of volcanoes (fig. 18.1), it appears that the volcanoes are associated with the weaker zones of the earth's crust and these are closely related with seismic events say earthquakes. The weaker zones of the earth's crust are represented by folded mountains and fault zones but the Alps and the Himalayas are exceptions. Occurrences of more volcanic eruptions along coastal areas and during wet season denote the fact that there is close relationship between water and volcanic eruption. Similarly, volcanic eruptions are closely associated with the activities of mountain building and faulting and fracturing. The mechanism of vulcanicity and volcanic eruption is closely associated with several interconnected processes, such as gradual increase of temperature with increasing depth due to heat generated from the disintegration of radioactive elements deep within the earth, origion of magma because of lowering of melting point caused by reduction in the pressure of overlying superincumbent load due to fracture, and ascent of magma forced by enormous volume of accumulated gases and vapour, which cause volcanic eruptions of violent central type or quiet fissure type depending upon the intensity of gases and vapour and the nature of crustal surface.

Theory of plate tectonics now very well explains the mechanism of vulcanism and volcanic eruption. Volcanic eruptions are very closely associated with plate boundaries. It may be pointed out that the types of plate movement and plate margins (boundaries) also determine the nature and intensity of volcanic eruptions. Most of the active fissure volcanoes are found along the mid-oceanic ridges. Two plates move in opposite directions from the mid-oceanic ridges. This lateral spreading of plates causes pressure release and therefore materials of upper mantle lying below the mid-oceanic ridges are melted and move upward as magma. This rise of magma along the mid-oceanic ridges causes fissure eruption of volcanoes through which there is constant upwelling of lavas (molten rock materials are called magma inside the earth but when they come on the earth's surface they become lavas). These lavas are solidified and added to the trailing ends of divergent plates and thus there is constant creation of new basaltic crust. The volcanic eruptions of Iceland and the islands located along the mid-Atlantic Ridge are caused because of seafloor spreading and divergence of plates. It is obvious that the constructive or divergent plate boundaries are always associated with quiet type of fissure flows of lavas because the pressure release of superincumbent load due to divergence of plates and formation of fractures and faults is a slow and gradual process.

On the other hand, destructive or convergent plate margins (boundaries) are associated with explosive type of volcanic eruption. When two convergent plates collide along Benioff zone, comparatively heavier plate margin is subducted below comparatively lighter plate. The subducted plate margin, after reaching a depth of 100 km or more inside the supper mantle, is melted and thus magma is formed. This magma is forced to ascend by the enormous volume of gases and vapour acumulated below and thus magma appears as violent volcanic eruption on the earth's surface. Such type of volcanic eruption is very common along the destructive or convergent plate margins which represent the volcanoes of the Circum-Pacific belt and the mid-continental belt.

The re-eruption of Mayon volcano in Philippines in February, 2000 and of Ashu volcano in April, 2000 in Japan validates the concept of occurrence of volcanic eruptions along destructive (convergent) plate margins. About 80,000 people were displaced due to re-eruption of Mayon.

The recent eruption of Merapi volcano of Java in 2006 and further triggered by Java earthquake of December 26, 2006 also validates the above theory.

Prediction of Volcanic Eruptions

Prediction of terrestrial natural hazards with near certainty could not be possible till now inspite of continued efforts of scientists. 'As in the case of earthquakes, the spatial distribution of volcanoes is well understood but the prediction of the timing of eruptions has had little success' (C. Embleton, 1989). A few characteristic features of volcanoes and their eruptions based on close observations of past volcanic eruptions are used as warning signs of impending eruptions but these warning signs, as elaborated below, cannot yield predictions with complete certainty. The following are the rudimentary measures and means of predictions of volcanic eruptions.

It may be pointed out, before enlisting the methods of prediction of volcanic eruptions, that crude generalization of eruption prediction is possible, and is generally done, only in those areas which have already been affected by volcanic eruptions. In other words, case histories of volcanic eruptions largely help in the eruption prediction.

The following steps are followed in predicting a dormant or extinct volcano :

➤ Regular measurement of seismic events and earth tremors by seismic methods give some clue for future eruptions. This principle is based on the basic tenet that the ascent of magma forced by enormous volume of gases and vapour below the earth's crust causes tremors and there is marked increase in the frequency and intensity of tremors just before the eruption occurs.

➤ Regular measurement of ground surface mainly **tilt measurement** in the possible localities by instruments such as 'tiltmeters' gives some indications of possible volcanic eruption. This method is based on the basic premise that there is deformation, though of very moderate nature, of the ground surface due to pressure exerted by ascending magma before the final eruption of a volcano. Some times the eruptions of volcanoes are so quick that no time is left for measuring the tilt or bulges in the ground surface. For example, 'the volcanic cinder cone of Monte Nuovo in Italy, 120 m high, followed just two years of increased seismic activity and a few days of minor ground uplift. The eruption of Mount St. Helens was, in the final few days before it exploded, better forecast, based on the alarming growth of a bulge in the side of the mountain, which later collapsed, releasing the cataclysmic outburst' (C. Embleton, 1989).

➤ Constant measurement of temperature of crater lakes, hot springs, geysers and fumaroles also gives some indications of possible eruption of a volcano in a particular locality because there is sharp increase in the temperature of waters. Thus regular readings and recording of water temperature in the areas of earlier volcanic eruptions give some warning signs of possible eruption.

➤ Similarly, monitoring of gases coming out of craters, hot springs, geysers, fumaroles etc. also helps in predictive purposes because there is variation in the composition of gases of these volcanic features before eruption.

➤ Monitoring of changes in the configuration of dormant or extinct volcanoes by laser gives valuable information and warning signs of volcanic eruption in some cases.

➤ Measurement of local gravity and magnetic field and their trends may also help in the prediction of possible eruptions. In fact, 'volcanoes situated at plate boundaries, erupting gas-charged, silicic (hence viscous) magma and pyroclasts, are particularly danagerous; they explode, and the instant of the explosion is almost impossible to predict. The beginning of a period of dangerous activity might be foretold by seismographs, tiltmeters, temperature monitors, or changes in gravity and magnetic fields' (F. Press and R. Siver, 1978).

➤ The path of lava flow also known as **'lahar'** (lava flow) can be better predicted on the basis of the detailed analysis of the topography and identification of possible eruptive points.

It may be pointed out that the eruption of a valcano cannot be stopped, even if predited well in advance, but its effects may be minimised. The direction of lava flow or **'lahar'** can be effectively diverted by building diversion walls and the speed of lava flows may be reduced by sprayng them with water.

Failure of Volcanic Prediction

The prediction of volcanic eruption is not always true because the eruption is related to the interior of the earth about which little is precisely known. Professor Landes of St. Pierre's College predicted about non-eruption of Mount Pelee Volcano on May 7, 1902 but it erupted on the following day i.e. May 8, 1902. The following description illustrates the unpredictiveness of volcanoes and disaster caused by a volcanic hazard.

Mount Pelee eruption of 1902 tells the dreadful story of total destruction of all humanity of a particular locality because of unprecedented volcanic eruption. It was 8.02 A.M. of May 8, 1902 when gloom and dispair loomed large over the coastal town of St. Pierre facing Mount Pelee on the Martinique island in the West Indes in the Caribbean Sea when a violent explosion of most disastrous volcanic eruption destroyed the whole of the town killing all the 28,000 inhabitants of the town leaving behind only two survivors to mourn the demise of their fellow persons. The type of volcanic eruption which destroyed the whole town of St. Pierre has been named as **nuee ardente** meaning thereby 'glowing cloud' or cloud of hot gas, lava etc. coming out of a volcanic eruption. The nuee ardente spread laterally out of the mountain (Mount Pelee) with great speed which caused disastrous avalanches on the hillslopes which plunged down the slopes at a speed of about 100 kilometers per hour. Consequently, the town of St. Pierre was engulfed by the emulsion of gas, glass, dust and lavas with shearing temperature of 8000°C. The gases were composed mostly of carbon dioxide and sulphur dioxide.

The inhabitants of St. Pierre town were so unaware of any possibility of eruption in immediate future that the sudden explosion of thunderous eruption caught them unaware and the helpless panicked victims had no alternative other than opting for their deaths. It is important to note that the prediction made by Professor Landes of St. Pierre's College only a day before the catastrophic eruption about non-occurrence of any volcanic eruption in near future once again was proved to be a futile exercise to predict the endogenetic events which are not discenible to human eyes. He predicted that 'The Montagne Pelee presents no more danger to the inhabitants of Saint Pierre than does Visuvius to those of Neples'. It is irony of fate that the predictor of the volcanic eruption was himself swallowed by the Peleean eruption. The destruction of Saint Pierre town was closely observed by Assistant Purser Thompson aboard his ship, the Roraima on may 8, 1902. He also surveyed the destruction of the town on the following day, May 9, 1902. The following are the descriptions of the events as presented by Thompson himself :

> "I saw St. Pierre destroyed. The city was blotted out by one great flash of fire. Nearly 40,000 people were killed at once. Of eighteen vessels lying in the roads, only one, the British steamship Roddam escaped and she, I hear, lost more than half of those on board. It was a dying crew that took her out. Our boat, the Roraima, arrived at St. Pierre early thursday morning. For hours before entering the roadstead we could see flames and smoke rising from Mt. Pelee. No one on board had any idea of danger. Caption G.T. Muggah was on the bridge and all hands got on deck to see the show. The spectle was magnificent......The mountain was blown to pieces. There was no warning. The side of volcano was ripped out and there was hurled straight toward us a solid wall of flame. It sounded like a thousand cannons. The wave of fire was on us and over us like a lightning flash. It was like a hurricane of fire, which rolled in mass straight down on St. Pierre and the shipping. The town vanished before our eyes and then the air grew stifling hot and we were in the thick of it. Wherever the mass of fire struck the sea the water boiled and sent up great clouds of steam. I saved my life by running to may stateroom and burying myself in the bedding. The blast of fire from the volcano lashed only for a few minutes. It shriveled and set fire to everything it touched. The burning rum ran in streams down every street and out into the sea. Before the volcano burst, the landings at St. Pierre were crowded with people. After the explosion, not one living soul was seen on land... The fire swept off the ship's mast and smoke stack as if they had been cut by a knife."

Success of Volcanic Prediction

The accurate prediction of the eruption of Kilauea volcano of Hawaii could be possible because of regular instrumentation and monitoring of all sorts of events occurring in and around dormant volcano. The following description depicts the story of prediction and eruption of the said volcano :

The Mauna Loa and Kilauea shield volcanoes of the southern Hawaii are the most instrumented and documented volcanoes of the world. A series of devices such as installation of volcano observatory maintained by the U.S. Geological Survey, modern network of seismographs, tiltmeters (instrument to measure the deformations of ground surface such as tilting, bulging etc.) and geochemical laboratory (to study the characteristics and systematic variations in the chemistry and petrology of the lavas and the chemistry of emitted gases) regularly monitor the tectonic activities in and around the Kilauea caldera. The final eruption of Kilauea volcano took place in the evening of 14th November, 1959 but several devices as mentioned above to monitor the prediction of the eruption of Kilauea provided vital information and clues before the final eruption, as follows :

- Seismographs detected a series of small seismic tremors of earthquakes having the foci at the depth of 55 kilometres below Kilauea caldera between August 14-19, 1959.
- Further weak tremors of seismic disturbances originating at the depths of 5 to 15 kilometres heralded the upward movement of magma in the conduits of older volcano,
- Substantial swelling of ground surface between August and October, 1959 as detected by tiltmeters showed the possible occurrence of volcanic eruption in the immediate future.
- The seismographs detected earth tremors of more than 1000 a day.
- Volcano observatory noticed the swelling of volcanic summit three times more in November, 1959.
- The number and intensity of quakes increased tenfold in the morning of November 14, 1959 indicating that the eruption was imminent and it actually happened as the violent volcanic eruption greeted the evening of 14th November, 1959.

The eruption of huge volume of lavas continued for seven days when about 30 million cubic metres of lavas poured out. The intermittent eruptions continued upto December, 21, 1959 when the volcano became dormant. The seismographs again detected a series of earth tremors in the first week of January, 1960 near Kapoho village, about 40 kilometers away from the Kilauea caldera. Finally, a flank eruption broke out on January 13, 1960. Within a period of four weeks of eruption about 100 million cubic metres of lavas poured out of one Kilometre long fissure which completely destroyed Kapoho village. It may be pointed out that though whole of the village was buried under thick layers of lava but no casualty could be recorded because of the fact that people were evacuated to safer places in the wake of correct prediction much before the time of actual eruption. The construction of 20-feet wall to halt the flow of lava down the slope or to divert the direction of flow path of lavas to save the seashore community could not prove to be effective.

Hazardous Effects of Volcanic Eruptions

As stated earlier volcanic eruption causes heavy damage to human lives and property through advancing hot lavas; fallout of volcanic materials; destruction to human structures such as buildings, factories, roads, rails and airports, dams and bridges, reservoirs, fires caused by hot lavas; floods in the rivers and climatic changes.

It is the speed of lava spread and movement down the cone slope that kills people and burn and bury human structure. In fact, lava flow does not give any time for the inhabitants living in the lower segments of dormant volcanic mountain to move to safer places. A few of the severe damages done by volcanic disaster may be summarized as follows :

(1) Huge volumes of hot and liquid lavas moving at considerably fast speed (recorded speed is 48 kilometres per hour) bury human structures, kill people and animals, destroy agricultural farms and pastures, plug rivers and lakes, burn and destroy forests etc. The great eruption of Mt. Loa on Hawaii poured out such a huge volume of lavas that these covered a distance of 53 kilometres down the slope. The Laki fissure flow of 1783 (Iceland) generated enormous volume of lavas which covered a very

large area which was equal to the geographical area of the Isle of Man. The thickness of lavas at places was 180 m or more. The cases of Mt. Pelee eruption of 1902 and Mt. St. Helens eruption of 1980 are representative examples of damages done by lava movement.

(2) Fallout of immense quantity of volcanic materials including fragmental materials, dusts and ash, smokes etc. covers ground surface and thus destroy crops, vegetations and buildings, disrupt and divert natural drainage systems, creates health hazards due to poisonous gases emitted during the eruption and causes acid rains.

(3) All types of volcanic eruptions, if not predicted well in advance, causes tremendous losses to precious human lives. Sudden eruption of violent and explosive type through central pipe does not give any time to human beings to evacuate themselves and thus to save them from the clutches of death looming large over them. As already mentioned, the sudden eruption of dormant volcano of Mt. Pelee on the island of Martinique, West Indes in the Caribbean Sea on May 8, 1902 destroyed the whole of St. Pierre town and killed all the 28,000 inhabitants leaving behind only two survivors to mourn the sad demise of their bretheren. Some times the volcanic eruptions are also followed by heavy rainfall. Thus the heavy downpour mixing with falling volcanic dusts and gases causes enormous mudflow or **lahar** on the steep slopes of volcanic cones which causes sudden death of human beings. For example, great mudflow created on the steep slopes of Kelut volcano in Japan in 1919 killed 5500 persons. Table 18.1 presents the example of human casualties caused by a few important volcanoes of the world.

(4) Earthquakes caused before and after the under sea volcanic eruptions generate destructive tsunamis seismic waves which create most destructive and disastrous sea waves causing innumerable deaths of human beings in the affected coastal areas. Only the example of Krakatoa eruption of 1883 would be sufficient enough to demonstrate the disastrous impact of tsunamis-generated sea waves as the enormous sea waves of 30 to 40 meters height generated by the explosive eruption of Krakatoa volcano in the Sunda Strait between Java and Sumatra killed 36,000 people in the coastal areas of these two islands.

Table 18.1 : Human casualties resulting from severe volcanic eruption

Year	Localities	Deaths
1902	Mt. Pelee, Martinique Island, West Indes, Caribbean Sea	28,000
1902	La Soufriere, St. Vincent	1,565
1919	Kelut, Japan	5,500
1951	Mt. Lamington, Papua	3,000
1963	Mt. Agung, Bali, Indonesia	1,500
1965	Mt. Taal, Philippines	500
1980	Mt. St. Helens, Washington, USA	70
1985	Columbia	23,000

Nothing can illustrate better the disastrous impacts of volcanic eruptions than the following statements of C.D. Ollier (1969) :

> "In the past 500 years volcanoes have probably killed, directly or indirectly, over 2,00,000 people (some other authorities put the figure on 3,00,000 people), of whom half died in the eruptions of Tamboro, Krakatoa and Mount Pelee. This toll is in fact very low when compared with those of earthquakes, floods, wars, or road accidents. On the credit side volcanoes provide fertile land, energy and materials for industry, and a livelihood for many people in the tourist trade. Even when activity has long ceased, most volcanic regions retain a great natural beauty, and frequently display most spectacular scenery. Such areas are often tourist attractions and a large number of National Parks are located on volcanic centres. On balance volcanoes do more good than harm."
> C.D. Ollier, 1969

J.E. Costa and V.R. Baker (1981) have summarized the magnitude of damages wrought by the eruption of an individual volcano with the example of the eruption of Mt St. Helens in 1980 in the state of Washington, U.S.A. in the following manner :

"The northward blast of the lateral eruption reduced the mountain's elevation by 396 m... ash was blown 19 km into the atmosphere. Waves of superheated dust and gas knocked down millions of trees. Mudflows filled lakes, rivers and streams, destroying fish, road and bridges...Two earthquakes of magnitude 5.0 were recorded during the eruption. The blast left a crater 1.6 km across and 900 to 1500 m deep......An estimated 4.2×10^9 m^3 of debris had been blown out of the volcano by the start of summer...the ash fall closed schools, factories, stores, offices, airports and highways, and idled 370,000 workers in Washington state...Damages from the eruption are estimated to be \$2.0 billion...Shipping on the Columbia river was halted by the Coast Guard because of sediment and log jams. The harbour of Portland was reduced in depth from 12 to 4 m in places by sedimentation..."

Environmental Impacts of Volcanic Eruptions

Besides the disastrous hazards caused by fallout of dust and gases, gas clouds, debris flows, breaking of crustal rocks and violent explosions, lava flows etc. during various types of volcanic eruptions, some more hazardous events of serious environmental consequences such as the formation of jokullhlaups, tsunamis and weather and climatic changes, are also caused due to volcanic eruptions.

Formation of Jokullhlaups : Jokullhlaups refer to the existence of enormous volume of water beneath the ice caps due to melting of ice caused by rise in temperature during the mechanism of vulcanicity. It so happens when a volcano erupts beneath the thick cover of ice sheets of an ice-cap. In such cases there are two possibilities viz. (i) If the volcanic eruption is strong enough and the temperature of erupted lavas is very high, the whole lot of ice sheets above is blasted and melted. (ii) But if the eruption is not strong and the heat is not sufficient enough to melt the whole ice sheets above, the ice sheet lying just above the volcano is callapsed and a big hole or depression is formed above the point of eruption. It is to be remembered that this hole is hidden beneath the overlying unmelted ice sheet. The water resulting from the melting of ice due to heat of volcanic eruption collects in the hole or depression. This ponding of ice melt-water or ice-damaged water is called jokullhlaups. Some times the volume of melt-water below the ice sheet becomes so enormous and the pressure becomes so high that the superincumbent ice sheet is broken and there is abrupt outburst of water causing flow of enormous volume of water. 'Individual flows have been known to exceed 400,000 m^3 per second, and a boulder 400 m^3 in size was carried 15 km by such a flow in Iceland in 1918. (For comparison, it is worth noting that the Amazon, which normally carries more discharge than any other river, has an estimated flow of about 200,000 m^3 per second)' (A. Goudie, 1984).

Volcanic Dusts and Climate Change : Enormous quantities of dust and ashes emitted into the sky during a volcanic eruption have been associated with weather and climatic changes at regional and global levels. It has been established by several atmospheric scientists that the formation of dust veils in the stratosphere whether due to volcanic eruption or from industrial sources or from atmospheric dust storms causes lowering of temperatures of the earth's surface and the lower atmosphere because (i) dusts reduce the amount of solar radiation reaching the earth's surface as they scatter and reflect some amount of incoming short wave solar radiation, and (ii) the dust veils do not hinder in the loss of heat of the earth's surface through outgoing longwave terrestrial radiation. In other words, the stratospheric dust veil (layer) does not block outgoing longwave radiation waves from the earth's surface and therefore it does not intensify the **greenhouse effects** as is done by the accumulation of carbon dioxide in the stratosphere.

Scientist Benjamin Franklin, while addressing to the Manchester Library and Philosophical Society in 1789 forcefully pleaded for a close link between volcanic activity and weather and climate. He presented the example of increased cold just after the explosion of Laki eruption (Iceland) in 1783-1784. Several attempts have been made to correlate global changes in temperatures with global activities of volcanic eruptions.

H.H. Lamb (1970 and 1982) 'has studied the link in great detail, showing conclusively that the dust veils that spread over a hemisphere or even the globe have effects on the weather that can last for up to seven years after an individual major eruption. It is even possible that increased volcanic activity was one of the factors responsible for the Little Ice Age, and some recent studies have suggested that the global cooling of the northern hemisphere after 1950 may have been caused by a marked increase of vulcanism over the same period' (C. Embleton, 1989).

The most forceful example to demonstrate the cooling effect of volcanic eruptions is the case of Krakatoa volcano which exploded on August 27, 1883 with a powerful blast with TNT equivalent of about 100 million tons. The ejection of nearly 20 cubic kilometres of fragmental materials, dusts and ashes upto the height of 23 kilometres in the atmosphere formed a thick dust veil in the stratosphere which caused a global decrease of solar radiation received at the earth's surface by 10 to 20 per cent. There was a total darkness in the sky in the vicinity of Krakatoa (between Java and Sumatra) because the dusts and ashes blotted out the sun for several days. The dust veil in the stratosphere and the circulation and drifting of dusts around the earth by upper air atmospheric circulations produced brilliant red sunsets for several years. 'However, the Krakatoa dust veil reduced by about 20 per cent the intensity of solar energy reaching the atmosphere in the first year following the explosion (in 1883). For each of the next three years the reduction (of solar energy reaching the earth's surface) was about 10 per cent. Eventually most of the dust settled into the lower atmosphere, and the blocking effect disappeared. A number of other large volcanic eruptions followed Krakatoa (in other parts of the world) in the 1880's and 1890's, but their effect as stratospheric dust producers seems to have been relatively less important' (A.N. Strahler and A.H. Strahler, 1976).

The disastrous fissure flow of Laki volcano of Iceland in 1783-1784 also caused severe winter in Iceland and its environs. 'In certain areas especially those with a more primative way of life, the volcanic fall-out and the ensuing weather changes have been known to cause economic disaster as in Iceland after 1783, and possibly in western Scotland after Hekla (volcanic eruption) in 1104 A.D.' (C. Embleton, 1989).

The gradual rise of temperature atleast in the northern hemisphere in the first half of the 20th century (1901 to 1950) upto 0.5°C has been attributed to a period of insignificant volcanic activity. According to a few scientists this rise in the temperature during the first half of the 20th century was because of the recovery of decrease in the temperature caused by Krakatoa eruption in the late 19th century. The sharp decline in the temperature in the northern hemisphere since 1940 has been ascribed to increased volcanic activity in this hemisphere such as eruption of Mt. Hekla in Iceland (1947), Mt. Spur in Alaska, U.S.A. (1953), Agung in Bali (1963), Mt. Helgafell in Iceland (1973). Mt. Taal, Philippines (1965), Mt. St. Helens in the state of Washington, U.S.A. (1980), in Columbia (1985) and a number of eruptions of lesser significance. Dr. Reid Bryson has related the cooling trend of temperature since 1940 to sharp increase in the atmospheric dusts contributed by 'Human Volcanoes' (chimneys of factories) because of increased pace of industrial development after second World War. The analysis of geomaterials obtained through the drilling of ice of the Antarictic ice-cap has revealed that there are evidences of the existence of the deposition of volcanic dusts dated about 20,000 to 16,000 years BP (before present) buried in the ice sheets. The dates of these buried volcanic dusts very much coincide with the phase of maximum cold of the last glaciation of Pleistocene period.

Volcanic Eruption and Ecological Changes : A group of scientists believe that volcanic eruptions and fallout of dusts and ash cause mass extinction of a few species of animals. Based on this hypothesis the mass extinction of dinosaurs about 60 million years ago has been related to increased world-wide volcanic activity. The second group of the scientists believes that the mass extinction of dinosaurs was caused because of the collision of a giant asteroid with the earth. 'New evidence suggests that both groups may be right and that the impact of an asteroid could have triggered the volcanic activity' (M. Rampino, 1990). The researchesrs have based their hypothesis on the discovery of high levels of a trace element, iridium, in the sediments deposited about 66 million years ago when many animals and plants including dinosaurs faced mass extinction, at the boundary between the Cretaceous and Teritary periods-the C/T boundary. The concept is based on the evidence of eruptions of modern volcanoes wherein it has been found that volcanic eruptions in Hawaii give off vapours which are rich in iridium. 'This (iridium) presumably comes from the deep mantle of the earth where such elements are more common than in the crust'. Some scientists believe that the Deccan eruptions of India during late Cretaceous and early Tertiary period might have caused mass extinction of animals.

According to Michael Rampino 'these results have led to a number of researchers to propose that the Deccan eruptions might have caused the extinctions. Recent calculations by our group at NASA's Goddard Institute for Space Studies in New York City suggest that the largest individual eruptions of flood basalt, which might have involved the production up to 1000 cubic kilometres of lava in less than a week, could have sent up enormous fountains of fiery lava, forcing ash and gases into the stratosphere. Large eruptions of basalt might have had widespread environmental effects, perhaps producing a severe 'winter' similar to a **'nucear winter'**, with acid rain, darkening of the sky and climatic cooling from dense clouds of sulphuric acid aerosols. Even if they are not the primary cause of the extinctions (of animals including dinosaurs), such eruptions could have made conditions deadly for many species of animals' (Michael Rampino, NIP, July 1, 1990).

Explosive type of volcanic eruptions and fallout of volcanic dusts and ash and accompanying acid rains also cause large-scale destruction of plants and animals. The annihilating eruption of Krakatoa in 1883 resulted in the sinking of 67 percent of the island and thus total destruction of plants of primary succession and animals. The fresh colonization of the newly built Krakatoa island by plants and animals took 50 years and thus secondary succession of vegetation on the newly built island could be possible because of dispersal of seeds from the nearby islands. The nearest island was only 40 km away from Krakatoa island.

Movement of enormous volume of hot lavas erupted from fissure flow through faults and fisures destroys vegetations and animals and thus causes ecological imbalance.

Volcanic Disaster Reduction

The reduction and management of volcanic disaster involves two major measures as follows :

(1) Prediction and early warning of eruption, and
(2) Timely evacuational and relief work.

It may be mentioned that the eruptions of volcanoes cannot be prevented and the loss of property cannot be avoided but human lives can be saved by timely prediction of eruption, forewarning and evacuation of people living in the vicinity of volcano.

As stated earlier the probable eruptions of volcanoes can be predicted with some degree of accuracy and certainty if the dormant volcanoes are properly and regularly instrumented and monitored. There are certain precursor events which help in the prediction of eruption of dormant and extinct volcanoes as given below :

- increase in the frequency of tremors, as recorded by seismographs,
- deformation of existing craters, as indicated by tiltmeter,
- rise in the temperature of water of crater lake,
- emission of gases and smokes from existing craters,
- restlessness of birds and animals etc.

The only effective preventive measure from the damages of impending volcanic eruption is to evacuate the people living on the lower segments of volcanic cone and nearby locality to safer places. It may be remembered that there is speedy flow of immense volume of hot and liquid lava down the slope of volcanic mountains and all the objects (vegetation, crops, houses, buildings, animals and people, if not evacuated in time) are burnt and destroyed and hence it is the timely evacuation of local population which alone can save human lives. If the lava flow is slow its speed can be minimized by using huge volume of water spray and chemicals.

Generally it happens that after long time interval people forget the previous event of eruption and lured by rich fertile black soils, the result of weathering of basaltic lava deposited during earlier eruptions, settle in the vicinity of dormant volcanic mountain unaware of the fact that they are living over explosive volcanic bomb. It is, therefore, necessary that people should not be allowed to settle down in the vicinity of a dormant volcano.

Precursor events gave regular indications since May, 2006, of imminent eruption of Mount Merapi volcano in Java (Indonesia). The pouring of superheated clouds of gases and lava from Mt Merapi was closely watched since its first sign of emission of gases in May, 2006. Feared from the unusual swelling of lava dome, its probable sudden collapse and speed of fast-moving lava and debris down into populated areas around mount Merapi in Magelang district, the government officials mobilised more than 40 trucks and motor cars and evacuated 11,000 villages from the foot-hill and nearby areas and put the inhabitants in temporary shelters such as tents, school buildings and other government buildings as precautionary measures in the 1st week of June, 2006.

18.3 EARTH QUAKE DISASTER

An earthquake is a major demostration of the power of the tectonic forces caused by endogenetic thermal conditions of the interior of the earth. 'An earthquake is a motion of the ground surface, ranging from a faint tremor to a wild motion capable of shaking building apart and causing gaping fissures to open in the ground. The earthquake is a form of energy of wave motion transmitted through the surface layer of the earth in widening circles from a point of sudden energy release, the 'focus' (A.N. Strahler and A.H. Strahler, 1976). The magnitude or intensity of energy released by an earthquake is measured by the **Richter scale** devised by Charles F. Richter in 1935. The number indicating magnitude or intensity (M) on Richter scale ranges between 0 and 9 but in fact the scale has no upper limit of number because it is a logarithmic scale. 'It is estimated that the total annual energy released by all earthquakes is about 10^{25} ergs, and most of this is from a small number of earthquakes of magnitude over 7' (A.N. Strahler and A. H. Strahler, 1976). The 1934 Bihar earthquake (India) measuring 8.4 magnitude on Richter Scale and Good Friday Earthquake of March 27, 1964, in Alaska, U.S.A. measuring 8.4 to 8.6 on Richter scale are among the greatest earthquakes of the world ever recorded. The following description of Richter scale may help in assessing the devastation caused by the energy release during earthquakes of varying magnitudes. 'The world's largest and most intensive recorded earthquake was of the magnitude of 8.9 (and 9.3) and the number of recorded earthquakes increases 10 times as magnitude decreases by one.'

Table 18.2 : Richter scale of earthquake magnitude

Magnitude	Description
o	Smallest earth tremor detected by seismograph only. Energy released by such insignificant earthquake amounts to 3×10^{12} ergs.
2.5 to 3.0	Such earthquakes may be felt and detected if they occur near the settlements. The annual frequency of such earthquakes is around 100,000. No damage is done.
4.5	Local damage is done.
5.0	The quakes of this magnitude equal in energy to ordinary atomic bomb. The atomic bomb hurled on Hiroshima (Japan) during Second World War equalled the magnitude of 5.7 on Richter scale. The energy released from such earthquakes equals 8×10^{20} ergs.
6.0	Such earthquakes become destructive within a limited area provided that the geological structure is weak and the area is heavily populated.
>6.0	Devastation increases with increasing magnitude.

Another scale of the measurement of the degree of destructiveness or intensity of earthquakes is **Mercalli scale**. The degree of destructiveness or intensity of an earthquake depends on a variety of factors e.g. magnitude, distance from epicentre, acceleration, duration, amplitude of waves, type of ground, water table, nature of geomaterials of the region concerned and the nature and type of constructions (such as buildings made of wood or bricks or stones or concretes, dams whether concrete or earthen, buildings made of muds, tin shades, huts etc.) affected by an earthquake. Table 18.3 represents the comparative picture of Mercalli Intensity Scale and Richter Magnitude Scale.

Table 18.3 : Comparative picture of Mercalli and Richter Scales

Mercalli Intensity	Description of Characteristic Effects	Richter Magnitude corresponging to highest intensity reached
I Instrumental	The tremors of this category of earthquakes are detected only by seismographs	
II Feeble	Such earthquakes are noticed by only sensitive people	3.5
III Slight	Like the vibrations caused by passing truck or lorry; felt by people at rest especially in upper floors of the buildings	4.2
IV Moderate	Felt by people while walking; rocking of loose objcts including standing vehicles	4.3
V Rather Strong	Felt generally, most sleeping people are awakened and bells ring	4.8
VI Strong	Trees sway and all suspended objects swing; damage is caused by overturning of vehicles and falling of loose objects	4.9-5.4
VII Very Strong	General alarm; walls crack; plaster falls	5.5-6.1
VII Destructive	Vehicle drivers seriously disturbed; masonry constructions are fissured, chimnyes fall; poorly constructed buildings damaged	6.2
IX Ruinous	Some houses callapse where ground begins to crack and pipes breack open	6.9
X Disastrous	Ground cracks badly; many buildings destroyed and railway lines bent; landslides on steep slopes	7-7.3
XI very disastrous	Few buildings remain standing; bridges destroyed, all serivces (railways, pipes and cables) out of action; great landslides and floods	7.4-8.1
XII Catastrophic	Total destruction; objects thrown into air; ground rises and falls in waves.	above 8.1

The place of the origin of an earthquake is called **focus** which is always hidden inside the earth but the depth of which varies from place to place. The deepest earthquake may have its focus at a depth of even 700 km below the ground surface but some of the major Himalayan earthquakes, such as the Bihar-Nepal earthquake of August 21, 1988, have their focus around 20-30 km deep. The place on the ground surface, which is perpendicular to the buried 'focus' or 'hypocentre', recording the seismic waves for the first time is called **epicenter**. The **seismic waves** move away from the source of the earthquake (focus or hypocentre) in the form of (i) primary or pressure waves (P waves), (ii) secondary, shear or transverse waves (S waves) and (iii) long waves or surface waves (Lwaves). These seismic waves are recorded with the help of an instrument called **seismograph** or **seismometer** at the epicentre. The patterns of recorded seismic waves are studied and various definite information about the centre of the origin of the earthquake (focus or hypocentre), magnitude and destructive power of the earthquake, probable cause of the earthquake etc. are received.

Magnitude and energy released during an earthquake is generally related to the effects of the earthquake in terms of human beings and his habitats. It is apparent from table 18.4 that most of the earthquakes occurring on the earth are small. On an average about 80,000 earth tremors are recorded by seismographs each year but most of them are not felt by human beings. Beno Guttenburg and Charles F. Richter have stated that the size (magnitude M) and the logarithm of frequency (number of earthquakes, N) of earthquakes in a given area of observation are linearly related. On the basis of this analysis one can calculate the probable return periods of earthquakes of different magnitudes. Great earthquakes, with magnitudes over 8, generally occur about once every 5 to 10 years. Earthquake of magnitude 8 or more has a probable return period of 50 years in North East India. Real damages caused by earthquakes begin at magnitude 5 and continue to increase to nearly total destruction in the neighbouring settlements by the earthquakes with more than 8 magnitude. Maximum recorded magnitude is 9.3 (Semeuleu, 2004).

Table 18.4 : Magnitudes, energies, effects and frequencies of earthquakes

Sl. No.	Characteristic effects of shocks in populated areas	Approximate magnitude (M)	Number of earthquakes per year (F)	Released energy (ergs)
1	Damages nearly total	≥ 8.0	0.1-0.2	$>10^{25}$
2	Great damage	≥ 7.4	4	$\geq 0.4 \times 10^{24}$
3	Serious damage, rails bent	7.0-7.3	15	$0.04\text{-}0.2 \times 10^{24}$
4	Considerable damage to buildings	6.2-6.9	100	$0.5\text{-}23 \times 10^{21}$
5	Slight damage to buildings	5.5-6.1	500	$1\text{-}27\times 10^{19}$
6	Felt by all	4.9-5.4	1,400	$3.6\text{-}57 \times 10^{17}$
7	Felt by many	4.3-4.8	4,800	$1.3\text{-}27 \times 10^{16}$
8	Felt by some	3.5-4.2	30,000	$1.6\text{-}76 \times 10^{15}$
9	Not felt but recorded	2.0-3.4	800,000	$4 \times 10^{19} - 9 \times 10^{13}$

Causes of Earthquakes

Earthquakes are caused due to disequilibrium in any part of the crust of the earth. A number of causes have been assigned to cause disequilibrium in the earth's crust such as volcanic eruptions, faulting and folding, upwarping and downwarping, hydrostatic pressure of man-made water bodies like reservoirs and lakes, and of late the plate movements. The occurrence of severe devastating earthquakes of San Fransisco (U.S.A.) in 1906 led H.F. Ried, one of the official investigators of San Fransisco earthquake disaster, to advance his important '**elastic rebound theory**' to explain the mode and causes of earthquakes mainly caused by fractures and faults in the earth's crust and upper mantle. Recently, '**plate tectonic theory**' has been accepted as the most plausible explanation of earthquakes. As per theory of the plate tectonics the crust of the earth is composed of solid and moving plates having either continental crust or oceanic crust or even both continental-oceanic crust. The earth's crust consists of 6 major plates (Eurasian plate, American plate, African plate, Indian plate, Pacific plate and Antarctic plate) and 20 minor plates. These plates are constantly moving in relation to each other due to thermal convective currents originating deep within the earth. Thus all the tectonic events take place along the margins of plates.

From the standpoint of movement and tectonic events and creation and destruction of geomaterials the plate boundaries are divided into 3 types.

(1) **Constructive plate boundaries** : are characterized by continuous addition of geomaterials as there is constant upwelling of molten materials from below along the mid-oceanic ridges. These molten hot materials (lavas) are cooled and solidified and are added to the trailing margins of the divergent plates. In fact, divergent plates move in opposite directions from the mid-oceanic ridges and there is always addition of new crust to the trailing ends of these plates because of cooling and solidification of molten lava.

(2) **Destructive plate boudaries** : are those where two convergent plates collide against each other and the heavier plate boundary is subducted below relatively lighter plate boundary. This results in constant loss of crustal materials.

(3) **Conservative plate boundaries** : are those where two plates pass past each other without any collision. This process results neither in the creation nor in the destruction of crust.

Major tectonic events associated with these plate margins are rupture and faults along the constructive plate margins; faulting and folding along the destructive plate margins and transform faults along the conservative plate margins. Thus these major tectonic events of faulting and folding and mountain building cause volcanic eruptions and earthquakes of varying magnitudes along different plate margins.

Normally, moderate earthquakes are caused along the constructive or divergent plate margins because the rate of rupture of the crust and consequent movement of plates away from the mid-oceanic ridges is rather slow and the rate of upwelling of lavas is also slow. Consquently, shallow focus earthquakes are caused along the constructive plate margins or say along the mid-oceanic ridges. The depth of focus of the earthquakes associated with the constructive plate margins ranges between 25 km to 35 km but a few earthquakes have also been found to have occurred at the depth of 60 km. It is thus obvious that the earthquakes occurring along the mid-Atlanic Ridge, mid-Indian oceanic ridge and East Pacific Rise are caused because of movement of plates in opposite directions (divergence) and consequent formation of faults and upwelling of magma (say vulcanicity, more specifically fissure flow).

Earthquakes of high magnitudes and deep focus are caused along the convergent or destructive plate margins because of collision of two convergent plates and consequent subduction of one plate margin along the Benioff zone. Here mountain builing, faulting and violent volcanic eruptions (central eruptions) cause disastrous earthquakes having the focus at the depth upto 700 km. The earthquakes having their focus upto 720 km depth have been recorded so far. This process, convergence of plates and related plate collision, explains the maximum occurrence of earthquakes of varying magnitudes along the 'circum-Pacific belt'(along the western and eastern margins of the Pacific ocean or say along the western coastal margins of North and South Americas and thus the Rockies-Andes mountain belt and along the eastern coastal margins of Asia and Island arcs and festoons parllel to Asiatic coast) and 'mid-continetal belt' (along the Alpine-Himalayan chains). The earthquakes of the western marginal areas of North and South America are caused because of subduction of American plate below the Pacific plate and resultant tectonic forces whereas the earthquakes of the eastern margins of Asia are originated because of subduction of Pacific plate under the Asiatic plate. Similarly, the subduction of African plate below Eropean plate and the subduction of Indian plate below Asiatic plate cause earthquakes of the mid-continental belt. Creation of transform faults along the conservative plate margins explains the occurrence of severe earthquakes of California (U.S.A.). Here one part of California moves north-eastward while the other part moves south-westward along the fault plane and thus is formed transform fault which causes earthquakes.

Distribution of Earthquakes

The world map of the distribution of earthquakes prepared by the seismologists on the basis of computer analysis and simulation of 30,000 earth-

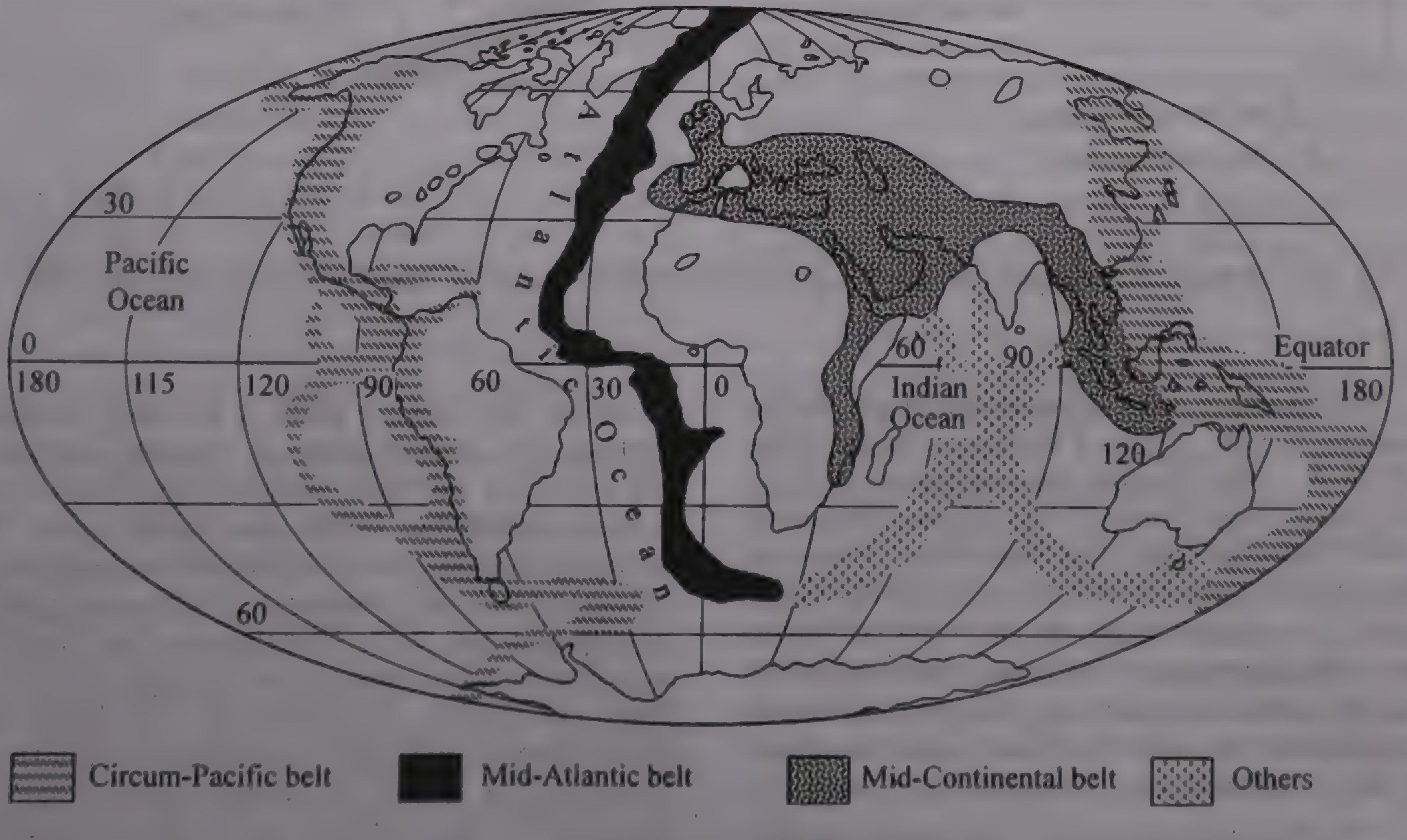


Fig. 18.2 : World distribution of earthquakes.

quakes that occurred between 1961 and 1967 very much coincides with the traditional map of world distribution of earthquakes (fig. 18.2) viz. (i) Circum-Pacific Belt or Ring of Fire surrounding the Pacific Ocean, (ii) Mid-Continental Belt representing epicentres located along the Alpine-Himalayan chains of Eurasia and northern Africa and epicentres of east African fault zone, and (iii) Mid-Altantic Belt representing the earthquakes located along the mid-Atlantic Ridge and its off-shoots. 'The high-quality seismicity maps showed that narrow belts of epicentres coincide almost exactly with the crest of mid-Atlantic (Ridge), the east Pacific, and other oeanic ridges, where plates separate. Earthquake epicentres are also aligned along transform faults, where plates slide past each other. But earthquakes that occur at depths greater than about 100 kilometres (60 miles) typically occur near margins where plates collide (fig. 18.3). It is a basic tenet of the theory of plate tectonics that these deep earthquakes actually define the positions of subducted plates which are plunging back into the mantle beneath an overriding plate' (F. Press and R. Siever, 1978). It may be pointed out that the occurrences of earthquakes along the plate margins (boundaries) are well explained on the basis of plate tectonic theory but the earthquakes originating within the plates are difficult to the explained on the basis of this revolutionary theory.

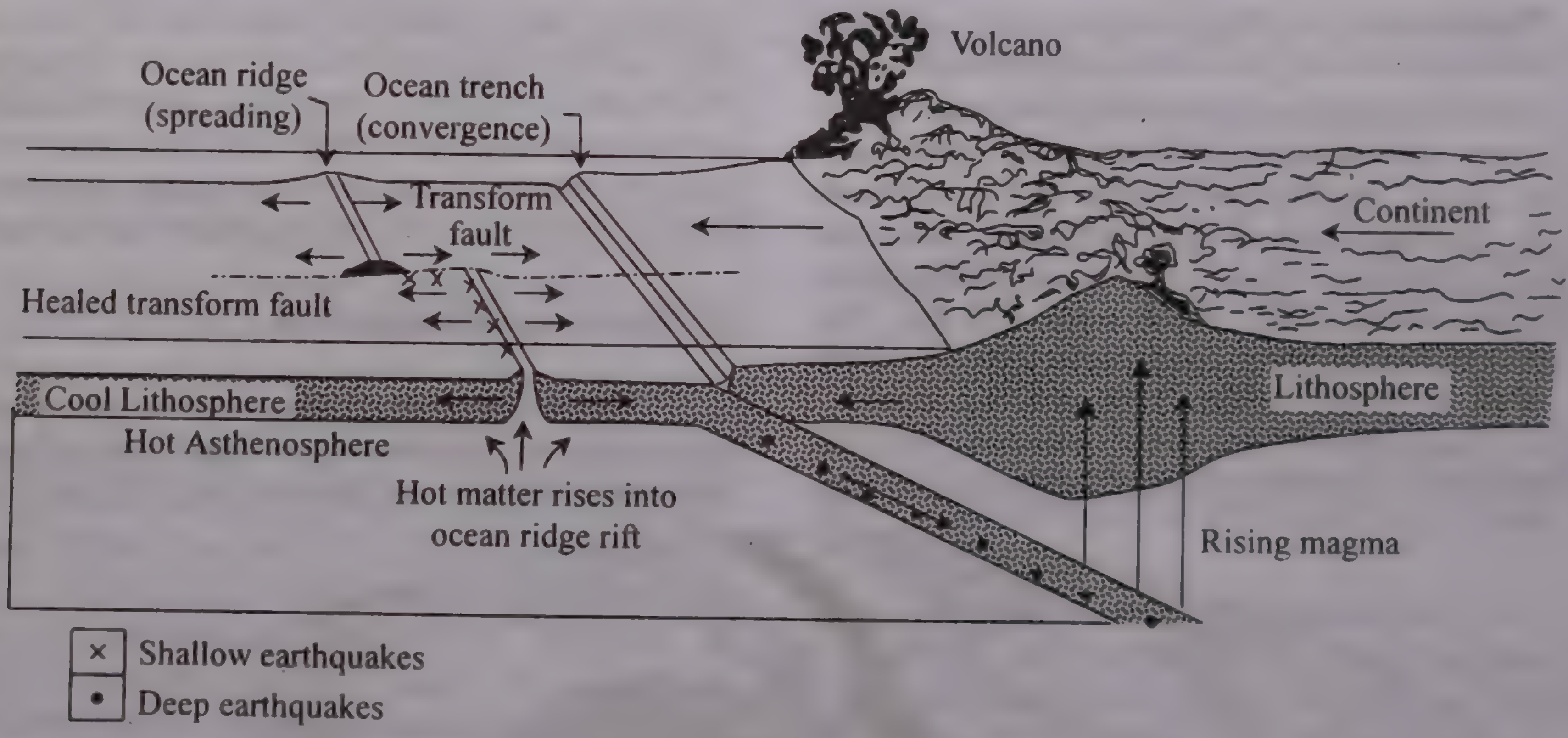


Fig. 18.3 : Relationships between earthquakes and plate margins (boundaries), after F. Press and R. Siever, 1978.

For example, the earthquakes of New Madrid (Missouri, U.S.A., 1812), Charleston, South Carolina (U.S.A., 1886), Boston, Massachusetts (U.S.A., 1755), Tang-Shan (China, 1976), Koyna (December 11, 1967, India) etc. are a few examples of intraplate earthquakes. Similarly, 'the seismicity of the Indian Shield as revealed from Kutch (1819), Koyna (1967), Bhadrachalam (1969) and Broach (1970) cannot be explained easily by plate tectonics since they occurred far away from the plate boundary' (J.G. Negi, in the Hindu, September 18, 1988).

The Indian earthquakes along the Himalayas and foo thill zones may be explained in terms of plate tectonics. The Asiatic plate is moving southward whereas the Indian plate is moving northward and hence the northern margin of the Indian plate is being subducted below the Asiatic plate. This collision of Asiatic and Indian plates and subduction of Indian plate and consequent folding and faulting and gradual rise of the Himalayas at the rate of 50 mm per year cause earthquakes of northern India and Tibet and Napal. According to J.G. Negi, P.K. Agrawal and O.P. Pandey (as reported in the Hindu, September 18, 1988) 'the Indian subcontinent has deformed at places due to the Indian Ocean floor spreading process. India folds at places and when the energy reaches the elastic limit, the rocks breakup and trigger strike-slip and thrust fault earthquakes. The Himalayan fault zone is not actually one fault but a broad system of interactive faults. It consists of a complex grid of faults extending all along this colliding zone. The earthquake belt extends from Sulaiman and Kirthar shear zones in the west, the Himalayas in the north and Burmese arc in the east'. These tectonic events caused by plate movements cause earthquakes in the northern and north-eastern parts of India.

Adverse Effects of Earthquake Disaster

It may be restated that the intensity of earthquakes and their hazardous impacts are determined not on the basis of the magnitude of seismic intensity as determined by Richter or Mercalli scales but are decided on the basis of quantum of damages done by a specific earthquake to human lives and property. An earthquake becomes disaster only when it strikes the populated area. Some times the moderate earthquakes on Richter scale inflict great damages by stimulating and augmenting other natural physical processes such as landslides, floods and fire. Thus it is obvious that it is not necessary that an earthquake creates havoc itself but it also becomes disastrous indirectly. It may also be mentioned that it is not the earthquake that inflicts more damage, rather it is the buildings of weak structures, that cause more damage and kill people. The direct and indirect disastrous effects of earthquakes include deformation of ground surfaces, damages and destruction of human structures such as buildings, rails, roads, bridges, dams, factories, destruction of towns and cities, loss of human and animal lives and property, violent fires, landslides, floods, disturbance in groundwater conditions etc.

1. Slope Instability, Slope Failure and Landslides

The shocks produced by earthquakes particularly in those hilly and mountainous areas which are composed of weaker lithologies and are tectonically sensitive and weak cause slope instability and slope failure and ultimately cause landslides and debris falls which damage settlements and transport systems on the lower slope segments. The Peruvian earthquake of May, 1970 tells the awesome story of disastrous tragedy inflicted by the said earthquake to the town of Yungay. The shocks generated by strong earthquake in May, 1970 triggered off the collapse of ice cap seated on the peak of high mountain called Huascaran of 6654 m height near the town of Yungay in Peru. Huge masses of falling ice dislodged thousands of tonnes of rock mass from the said mountain and thus was generated a gigantic debris flow down the slope of Huascaran mountain travelling at the speed of 320 kilometres per hour. The volume of debris flow further increased down the slope because more and more debris and water joined the main debris flow route. This enormous mass of debris flow covered a distance of 15 kilometres within few minutes. The enormity of the mass of debris may be gauged from the fact that individual rock blocks measured about 15 cubic metres. This enormous debris fall triggered by earthquake buried many buildings and human structures of Yungay town and killed about 25,000 people.

The second example of slope failure and resultant landslides caused by earthquakes may be cited from the Tajik earthquake of 1989. 'The Tajik earthquake in the south of the former USSR on 21 January 1989, for example, was only of magnitude 5.5, but its timing unfortunately coincided with highly unstable slope conditions caused by high pore-water pressure resulting from snow-melt. Huge landslides and rivers of mud 20 m deep were set off that engulfed houses and even whole villages. This is seismically a highly active region, shaken by upwards of 3000 tremors a year, but these cause few direct casualties—it is the effects on other natural processes that are disastrous' (C. Embleton, 1989, in Aerospace Survey and Natural Disaster Reduction, ITC, Enschede, Netherlands, 1989).

The Chamoli quake followed by a series of seismic events in Uttarakhand (India) in 1999 triggered killer Malpa landslides which killed all the 200 piligrims, on way to Mansarovar, which were camping in Malpa village in the night.

The occurrence of earthquakes during wet season in the hilly and mountainous regions causes landslides even if the earthquakes are of very moderate nature. This is the reason that people notice earth tremors through landslides during wet season but fail to notice such earth tremors during dry season of the year. 'Landslides are often triggered by earthquakes in mountainous zones, especially in the wet season. I was baffled once when a farmer in southern Italy asked me 'why do earthquakes always occur in winter?. Until I realized that quakes occurring during the dry summers, when most slopes are stable, may hardly be noticed by the peasants' (H.T. Verstappen, 1989, in Aerospace Survey and Natural Disaster Reduction, ITC, Enschede, Netherlands, 1989).

2. Damage to Human Structures

Earthquakes inflict great damage to human structures such as buildings, roads, rails, factories, bridges and thus cause heavy loss of human property. In fact, the principal damage emanating from earthquake disaster is construction failure. It may be pointed out that the extent of damage done to the human structures not only depends on intensity and magnitude of earthquakes but also on the characteristics of ground upon which the buildings are constructed and the nature of materials of which the buildings have been constructed (such as stones, bricks, muds, concrete, cement, tins, huts etc.). It may be stated that if the ground surface composed of unconsolidated geomaterials such as alluvium, colluvium, artificially filled up and levelled up depressions, swamp deposits reclaimed through the dumping of coarse sands and city garbages, vibrations of earthquakes last longer and the amplitudes of seismic waves are greater than in the structure of consolidated materials and bedrocks. Thus the earthquakes cause more damages in the areas of unconsolidated ground than their counterparts in the regions of solid structures and bedrocks.

Two major earthquakes of Bihar (India)-Nepal border in 1934 and 1988 (Darbhanga quake) explain the impact of earthquakes disasters on human structures and human lives. It was the afternoon of 15th January 1934 when a powerful earthquake of the magnitude (M) 8.4, one of the greatest seismic events of the world, struck the northern Bihar plain (a part of the Ganga plain) and the Himalayan country of Nepal and adjoining Tibet. The epicentre of the earthquake was located at 26.6^0 N and 86.8^0 E (near Darbhanga in Bihar, India). The damages caused by this disastrous earthquake in India (Bihar), Nepal and Tibet include 10,700 human deaths, landslides and slumping in an area of 250 km length and 60 km width, ruptures in the ground surface, faults etc. which caused irreparable damage to human structures. This area remained more or less seismically dormant (as regards severe earthquakes only) except ordinary earth tremors, for more than 54 years but was suddenly struck by devastating hazardous earthquake in the morning hour of August 21, 1988. 'Once again the epicentre was located near Darbhanga town (towards Bihar-Nepal border) and the focus may lie 20-30 km deep at the intersection of Patna fault (or nearby parallel fault) and Himalayan frontal thrust. The seismic energy of the 1988 earthquake (6.5 magnitude on Richter scale) was 1000 times smaller than the great earthquake of 1934 (with magnitude of 8.4 on Richter scales as referred to above) but more than 850 people were killed, thousands injured in India and Nepal, with an earth surface split up at many places and more than 25,000 houses dmaged. The damage is high (inspite of comparatively lower magnitude of 6.5 than the higher magnitude of 8.4 of 1934 Bihar earthquake) due to the location of the affected area in the unconsolidated Gangetic alluvium which acts like a seismic amplifier' (J. G. Negi, 1988, in The Hindu, September 18, 1988). It may be pointed out that a fortnihgt ago the North-Eastern India was rocked by more severe earthquake (magnitude being 7.3 on Richtre scale, epicentre being near Imphal, Manipur, India) on August 6, 1988 but the damage was insignificant because of the fact that ground materials of N-E India are consolidated. Many of the houses damaged in Bihar because of Darbhanga earthquake of 1988 were quite old and were constructed by bricks and muds.

The recent earthquakes of October 8, 2005 in Pakistan Occupied Kashmir (Pok) and May 27, 2006 quake of Java flattened all the buildings and other human structures and rendered millions of people homeless.

'Ground vibrations can shake structures and stress them to the point of failure and collapse. The ground accelerations caused by great earthquakes can approach and even exceed that of gravity near the epicentre, and very few man-made structures can survive without severe damage. Certain kinds of soils loose their rigidity and "liquefy" when subjected to repeated seismic shocks' (F. Press and R. Siever, 1978). It may be mentioned that it is not only the vibrations caused by earthquakes which damage buildings directly but unconsolidated geomaterials of the ground surface are compacted by these vibrations because the particles move closer and are aggregated to form dense arrangement. 'As a consequence ground subsidence occurs, and this too can damage buildings. The ground locally subsided 0.6 m by compaction of sediments in the 1906 San Fransisco earthquake, and by 1.8 m during the 1964 Alaska earthquake (U.SA.). The consequence on settlement will be especially severe if building foundations are built across deposits of varying physical properties, which would cause one part of the foundations to settle more than another' (A. Goudie, 1984).

Table 18.5 : Some of the world's worst earthquakes in terms of human deaths, upto 19th century

Year	Place of occurrence	death	Year	Place of occurrence	death
856	Corinth, Greece	45,000	1737	Calcutta, India	300,000
1038	Shansi, China	23,000	1755	Northern, Perisa	40,000
1057	Chihli, China	25,000	1755	Lisbon, Portugal	30,000-60,000
1170	Sicily	15,000	1783	Calabria, Italy	50,000
1268	Silicia, Asia Minor	60,000	1797	Quito, Ecuador	41,000
1290	Chihli, China	100,000	1812	Venezuela	10,000
1293	Kamakura, Japan	30,000	1819	Kutch, India	1,500
1456	Naples, Italy	60,000	1822	Aleppo, Asia Minor	22,000
1531	Lisbson, Portugal	30,000	1828	Echigo (Honshu), Japan	30,000
1556	Shen-Shu, China	830,000	1847	Zenkoji, Japan	34,000
1667	Shemaka, Caucasia	80,000	1868	Peru and Ecuador	25,000
1693	Catania, Italy	60,000	1875	Venezuela and Colombia	16,000
1693	Naples, Italy	93,000	1896	Sanriku, Japan	27,000
1731	Peking, China	100,000	1897	Assam, India	1,500
			1898	Japan	22,000

Table 18.6 : Some of the world's major earthquakes in terms of human deaths, property loss, between 1900-1950

Year	Place of occurrence	death	Year	Place of occurrence	death
1905	Kangra, India	20,000	1932	Sagami Bay, Japan	250,000
1906	Valparaiso, Chile	1,500	1934	Bihar, India	10,700
1906	San Francisco, USA	500	1935	Quetta, Baluchistan	60,000
1907	Kingston, Jamaica	1,400	1939	Chile	40,000
1908	Messina, Italy	160,000	1939	Erzincan, Turkey	40,000
1915	Avezzano, Italy	30,000	1948	Fukai, Japan	5,000
1920	Kansu, China	180,000	1949	Ecuador	6,000
1923	Tokyo, Japan	163,000	1949	Khait, former USSR	12,000
1930	Apennine Mountains, Italy	1,500	1950	Assam, India	1,500
1932	Kansu, China	70,000			

Table 18.7 : Some of the world's major earthquakes in terms of human deaths, and property loss between 1951 and 2000 A.D.

Year	Place of occurrence	death	Year	Place of occurrence	death
1953	North western Turkey	1,200	1976	New Guinea	9,000
1954	Northern Algeria	1,600	1977	Romania	1,581
1956	Kabul, Afghanistan	2,000	1978	Tabas, Iran	25,000
1957	Northern Iran	2,500	1979	Yugoslavia	131
1957	Western Iran	1,400	1980	Algeria	2,590
1957	Outer Mongolia	1,200	1980	Italy	3,114
1960	Agadir, Morocco	14,000	1982	Yemen	3,000
1960	Southern Chile	5,700	1983	Colombia	250
1962	North western Iran	14,000	1985	Chile	200
1963	Skopje, Yugoslavia	1,000	1985	Maxico (8.1)	10,000
1968	Dasht-e-Bayaz, Iran	18,600	1986	El Salvador	1,000
1970	Chimbote, Peru	67,000	1987	Ecuador	1,000
1872	Managua, Nicargua	10,000	1988	Darbhanga, Bihar	850
1974	West Central China	20,000	1988	Armenia (6.9)	26,000
1975	Haicheng, China	10,000	1990	Iran (7.5)	50,000
1976	Italy	23,000	1990	Philippines	500
1976	Guatemala	23,000	1995	Japan (7.2)	6,000
1976	Tang-Shan, China	750,000	1998	Afganistan (6.9)	5,000
1976	Philippines	3,100	1999	Columbia (6.0)	1,171
			1999	Turkey (7.4)	17,000

Table 18.8: Devastating severe earthquakes of 20th and 21th centuuries with their magnitude and death toll

Year	Place of Occurrence	Magnitude (Richter Scale)	Deaths (maximum estimates)	Year	Place of Occurrence	Magnitude (Richter Scale)	Deaths (maximum estimates)
1905	Kangra Valley, India	8.6	20,000	1962	Buyin-zara, Iran	7.3	14,000
1907	Afghanistan	8.1	12,000	1968	Dasht-e-Bayaz, Iran	7.3-7.9	18,600
1908	Messina, Italy	7.5	200,000	1970	Chimbote, Peru	7.8-7.9	67,000
1915	Avenzzaro, Italy	7.5	30,000	1974	West Central China	6.8	20,000
1917	South Java		15,000	1975	Haicheng, China	7.3-7.4	10,000
1918	South-East China	7.3	10,000	1976	Guatemala	7.5	23,000
1920	Kansu, China	8.5	180,000	1976	Tang-shan, China	7.8-8.1	750,000
1923	Tokyo-Yakohama	8.3	163,000	1978	Tabas, Iran	7.7-7.8	25,000
1927	Nanshan, China	8.0-8.3	180,000	1985	Mexcio-city, Mexcio	8.1	10,000
1933	North-Central China	7.4	10,000	1988	Armenia	6.9	26,000
1934	Bihar, India	8.4	10,700	1988	Darbhanga (Bihar, India) and Nepal	6.5	850
1935	Quetta, Pakistan	7.5-7.6	60,000				
1939	Chillan, Chile	8.3	40,000	1990	Northern Iran	7.3	50,000
1939	Erzincan, Turkey	8.0	40,000	1990	Manila, Philippines	7.7	500
1948	Kagi, Formosa (Taiwan)	7.3	19,800	1990	(June) Iran	7.3	40,0000
1960	Agadir, Morocco	5.6-5.9	14,000				5,00,000 homeless

Year	Place of Occurrence	Magnitude (Richter Scale)	Deaths (maximum estimates)
1995	(January) Kobe, Japan	7.2	5,502 dead 2,80,00 homeless
1997	(May) Jabalpur (India)	6.0	50
1997	(May Iran	7.1	2,500
1998	(February) Afghanistan	6.1	4,400 15,000 Families homeless
1998	(29 May) Afghanistan	6.9	more than 5000
1998	(17 January) Kobe Janan	...	Over 5,000 23,600 injured
1999	(17 August), Turkey	7.4	Over 40,000 more than 19,000 wounded
1999	(12 November) Turkey	7.2	550
1999	(21 Stptember), Taiwan	7.3	more than 2000
2001	(January 26), Bhuj (India)	8.1	50,000 to 100,000
2002	Afghanistan (March 25)	5.8	1,000
2003	(May, 22), Algiers (Algeria)	6 7	2300 dead > 5000 wounded
2005	(Oct., 8) Muzaffarabad (POK)	6.5	>50,000 dead
2006	(May, 27,) Java	6.5	>5700
2009	(30 Sept) Penang (Sumatra)	7.6	a few thousand
2010	(Jan, 12)Port-au-Prince (Haiti)	7.0	2,30,000

Table 18.9: Major earthquake hazards of India

Time and magnitude	Location	Effects
October, 11, 1737	Calcutta	3,00,000 deaths of human beings, the worst earth quake of India in its seismic history.
September 1, 1793	Mathura	Adversely affected larger areas including Garhwal, Kumaun and Simla hills
June, 16, 1819	Kutch	2,000 people died, Bhuj city destroyed, famous mosque of 15th century in Ahmedabad city broken, rise of land in a length of 15 km in the Rann of Kutch known as Allah Bund
June 16, 1828	Kashmir	1,000 people died
August 26, 1833	Bihar	Adversely affected the areas from Bihar to Nepal; 1000 houses destroyed.
February 19, 1842	Jalalabad	Adversely affected the areas from Delhi to Kabul city of Afghanistan.
April 1, 1843	Deccan India	Carnool, Solapur, Belgaon and Bellary cities greatly damaged.
January 10, 1869	Assam	Adversely affected a large area of 2,50,000 square miles
May 30, 1885	Kashmir	3,000 people died
July 14, 1886	Dacca (Bangladesh) & W. Bengal	Adveersely affected large area of West and East Bengal, Assam, Sikkim, Bhutan and Chotanagpur covering an area of 2,30,000 square miles.
June 12, 1887 (8.7)	Shillong (Meghalaya)	1500 people died; houses even of stones in the cities of Naogaon, Shillong, Gauhati (Guwahati), Golpara etc. heavily damaged and destroyed; affected area 17,50,000 square miles, a great fault of 35 feet width and 12 miles length formed in the ground

June 15, 1890	Kutch	1500 people died
April 4, 1905 (8.6)	Kangra	20,000 people killed, whole Punjab was affected
July 8, 1918	Assam	...
July 3, 1930	Assam (Dhubri)	Dhubri town destroyed
January 5, 1934	Bihar-Nepal	8.4 Magnitude on Richter scale; 10,700 people killed
June 26, 1941	Andman	...
August 15, 1950 (8.7)	Assam	1500 people killed; 60 after shocks; floods in the rivers of Assam
May 18, 1955	Nicobar (Andman)	...
August, 1956	Kutch	...
September, 1956	Bulandshar	...
December 11, 1967 (6.5)	Koyna (Satara)	1000 people killed; 2063 wounded and 10,000 homeless
August 21, 1988	Darbhanga (Bihar)-Nepal	Magnitude 6.7 on Richter scale, 850 people died, 25,000 houses damaged
October 20, 1991 (6.6)	Uttar Kashi (Uttarakhand)	Over 2500 dead
September 30, 1993 (6.3)	Latur (Maharashtra)	11,000 dead
May 22, 1997 (6.0)	Jabalpur (M.P.)	50 dead
March 29, 1999 (6.8)	Chamoli (Uttarakhand)	50 dead
January 26, 2001 (8.1)	Bhuj (Gujarat)	50,000 to 100,000 dead
Dec. 26, 2004 (9.3)	Sumatra tsunami	> 250,000 dead in Indonesia, Thailand, India, Sri Lanka etc.
Oct. 8, 2005 (6.5)	POK (Muzaffarabad)	> 50,000 dead
Sept. 18, 2011 (6.8)	Mangan (Sikkim)	> 100 dead, about 1,00,000 houses and buildings collapsed

3. Damage to Towns and Cities

Earthquakes have their worst effects on buildings and large agglomerations of human population. The earth tremors of higher magnitudes shake the ground to such an extent that the large buildings collapse and men and women are buried under the large debris and rubbles of collapsed structural materials of buildings, ground water pipes are bent and damaged and thus water supply is totally disrupted, electric poles are uprooted and electric and telephone wires and cables are heavily damaged causing total disruption of electric supply and telecommunication systems, obstruction and dstruction of sewer system causes epidemics, road blocks throw the transport systems out of great etc. Kolkata city was severaly damaged due to sever earthquake of October 11, 1737 and tidal surges as thousands of buildings were severly damaged and 3,00,000 people were killed. Nearly 2,00,000 people were killed within a period of 100 years due to earthquakes of 1688, 1693 and 1783.

The example of severe hazardous earthquake of mexico city of September, 1985 tells the story of disastrous effects of seismic hazards on human structures and property. Though the epicentre was located about 400 km south-west of Mexico city, the capital of Mexico, but greatest damage was caused in Mexico city. It is believed to be the strongest earthquake in Latin America in last 100 years or so. The total destruction caused by this earthquake includes death toll 10,000; missing people 2000; injured people 40,000; buildings collapsed-400; buildings severly damaged 6000; moderately damaged buildings 50,0000; total loss of property 4000 million US dollars; loss of Gross National Product (GNP) 136 billion US dollars. Besides, the infrastructures of the city were seriously damaged, for example, water pipes were broken, telecommunication lines and systems were severly damaged, power and water supplies were disrupted, inner vehicular transport was halted etc.

(4) Loss of Human Lives and Property

The destructiveness of an earthquake is determined on the basis of human casualties in terms of deaths. Some of the world's worst earthquakes in terms of human deaths during 19th century (table 18.5), first half of 20th century (table 18.6) and in the later half of the 20th century (table 18.7) have been listed in tables 18.5 to 18.7 and severe hazardous earthquakes causing heavy toll of human lives during the 20th and 21st centuries have been shown in table 18.8. It is apparent from table 18.8 that it is not the magnitude (intensity) of earthquake alone which matters more as regards the human casulaties but it is the density of human population and houses which matter more in terms of human deaths and loss of property. For example, the Kangra earthquake of India in 1905 recorded 8.6 magnitude on Richter scale but it could cause death of only 20,000 persons whereas 1976 Tang-shan earthquake of China measuring 7.8 to 8.1 on Richter scale caused deaths of 750,000 persons.

From the stand point of human casualties earthquake disasters are divided into the following 3 categories :

(1) **Disastrous earthguakes** : represent earthquakes which claimed human death toll ranging between 20,000 to 50,000 (table 18.10) :

Table 18.10 : Disastrous earthquake (death toll, 20,000-50,000)

Year	Location	Human casualties
1971	China	20,000
1293	Kamakura, Japan	22,000
1731	Peking, China	22,000
1555	Shen-Shu, China	25,000
1980	Armenia	26,000
1896	Sanriku, Japan	27,000
1828	Honshu, Japan	30,000
1755	Northern Persia	40,000
1939	Chile	40,000
1939	Erzincan, Turkey	40,000
1797	Quito, Equador	41,000
856	Corinth, Greece	45,000
1783	Calabria, Italy	50,000
1990	Northern Iran	>50,000

(2) **Highly disastrous earthquakes** : causing human deaths ranging between 51,000 and 100,000 as shown in table 18.11.

Table 18.11 : Highly disastrous earthquakes (death toll, 51,000-100,000)

Year	Location	Human casualties
2005	Muzaffarabad, POK	>50,000
1268	Silicia, Asia Minor	60,000
1667	Shemaka, Caucasia	60,000
1693	Catania, Italy	60,000
1693	Naples, Italy	60,000
1970	Chimbote, Peru	67,000
1932	Kansu, China	70,000
1935	Quetta, Baluchistan	93,000
2001	Bhuj, Gujarat, India	50,000-100,000

(3) **Most disastrous earthquakes** : are those which have claimed lives of more than 100,000 persons. Table 18.12 displays the occurrences of most disastrous earthquakes causing more than 100,000 human casualties.

Table 18.12 : Most disastrous earthquakes (human deaths > 100,000)

Year	Location	Human deaths
1290	Chihli, China	100,000
1908	Messina, Italy	160,000
1932	Tokyo, Japan	163,000
1920	Kansu, China	180,000
1923	Sagami Bay, Japan	250,000
1737	Kolkata, India	300,000
1976	T' ang-Shan, China	750,000
1556	Shen-Shu, China	830,000
2010	Port-au-Prince (Haiti)	2,30,000

A case history of disastrous earthquake of northern Iran which occurred in the month of June, 1990 may demonstrate the aweful calamity of the devastating natural hazard borne by human society. The degree of devastation caused by the earthquake may be gauged from the fact that Mr. Ali Akabar Hashemi Rafsanjani, the then President of Iran, decalred three days of official national mourning and called on the Iranian people to mobilize for relief and rscue operations.

The dreadful killer earthquake occurred at 12.31 A.M. on June 21, 1990 and measured 7.3 on Richter scale as recorded by Iranian seismologists but it was recorded by Indian and American seismologists as 7.7 on Richter scale. The quake jolted the provinces of Tehran, Gilan, Mazandaran, East Azarbaijan and Hamedan. The epicentre of the earthquake was located in Daylaman between Langround and Lahijan in the Gilan province, 70 km away from the Caspian Sea. The killer quake devastated towns and flattened whole villages across mountains, valleys and lush coastal plains of Caspian Sea in an area of 150 km width in the northern part of Iran and thus killed more than 50,000 persons (some agencies estimated the death toll to be more than 100,000 mark) and injured more than 100,000 people. It may be pointed out that Iran's most disastrous earthquake of the past two decades was recorded and felt in 1978 when 25,000 people were killed around the eastern desert town of Tabas but this quake has surpassed the killer effects of all the past seimsmic events recorded in Iran. Main roads linking Rasht,the provincial capital of Gilan, to the major cities were blocked by massive landslide triggered by the quake. The hardest hit cities were Lahijan, Langround, Astaneh, Ashrafiyeh, all in Gilan province neartest to the epicentre of the quake. Even buildings shook and window broke in Tehran sending frightened residents fleeing into the streets. The quake left scroes of villages located at the slopes of the Alborz mountains between the Caspian Sea and Zanjan in a total ruin. Some of the rubbles appeared to have rolled hundreds of metres down the slopes. Many of the houses have sunk deep into the earth. About 100,000 persons were rendered homeless.

Loss of property and Gross National Product (GNP) due to disastrous earthquakes which occurred between 1960 and 1987 has been shown in table 17.1 in chapter 17 of this book. Great damage of human property worth 5.6 billion US dollars was done in China (in T' ang shang) by July 1976 earthquake measuring 7.8 to 8.1 on Richter scale which amounted to 280 billion US dollars GNP of the country. Peruvian earthquake of 1970 (Chimbote) measuring 7.8 to 7.9 on Richter scale caused damage to property worth 500 million US dollars. The huge damage to human property worth 10 billions US dollars was done by the earthquake of November, 1980 in Italy. Only four years back property of 3.6 billion US dollars was destroyed by the earthquake of May, 1976 in Italy. Mexican earthquake of September, 1985 (Mexico city) claimed loss of human property worth 4 billion US dollars. The property loss includes destruction of houses, government and public establishments, roads, rails, bridges, vehicles of several sorts, power houses, power lines, pipe lines, cables, shops, crops, cattle and of course most precious human lives.

(5) Severe Fires

The strong vibrations caused by severe earthquakes strongly shake the buildings and thus strong oscillations cause severe fires in houses, mines and factories because of overturning of cooking gas cylinders, contact of live electric wires, chirning of blast furnaces, displacement of other electric and fire-related appliances. For example, the housewives were cooking their lunches in the kitchens when disastrous killer earthquakes struck in the vicinity of Tokyo and Sagami Bay in 1923. Consequently, severe fire broke out which claimed the lives of 38,000 peope out of total fatalities of 1,63,000 caused by the eartquake through various processes. This earthquake resulted into total loss of property worth 2500 million US dollars. The severe earthquakes of San Francisco (USA) which occurred on April 18, 1906, caused fires in several parts of the city. No water could be made available immediately to extinguish the fire because water pipes were also broken and displaced by the earthquake. This delay in fire-fighting resulted in the destruction of major portions of the city.

(6) Ground Deformation

Severe earth tremors and resultant vibrations caused by severe earthquakes result in the deformation of ground surface because of rise and subsidence of ground surface and faulting activity. For example, the Alaska earthquake (USA) of 1964 caused displacement of ground surface upto 10-15 metres. 'Some seismic movements are more gradual, and occur by a process called **seismic creep.** Although their effects are less immediately dramatic, detailed surveys with precise levelling instrumetns in parts of California, where there are major faults like the Garlock and San Andreas, reveal movements of 5-13 m in 1000 years' (A. Goudie, 1984). The 1987 Assam earthquake of India caused a large fault measuring 35 feet (10.6m) long and 12 miles (19.3 km) wide. Several faults were careated in the mouth areas of the Mississippi river because of the earthquakes of 1811, 1812 and 1813 in the Mississippi valley. The alluvial-filled areas of the flood plains of the Mississippi were fractured at many places which forced ground surface at few places to collapse. This process resulted into the formation of lakes and marshes.

The ground surface was greatly deformed in the delta area of the Indus river (Pakistan) due to the earthquake of 1819 as an area of 45,000 square kilometres was subsided to such an extent that this was submerged beneath sea water and this land area disappeared for ever. It may be pointed out that subsidence in one area is followed by emergence of the land in other area. This also happened in the Indus delta area as a large area measuring 80 km in length and 26 km in width was raised by 3 m from the surrounding area.Similarly, the coastal land of Chile was raised from 6 m to 13 m because of the earthquake of 1835. The sea-floor of Sagami Bay of Japan was subsided from 30 m to 457 m because of the earthquake of 1923.

(7) Destruction of Dams and Flash Floods

Strong seismic events result in the damages of dams and cause severe floods. A possible disastrous flash flood was averted by prompt action of local authorities in the San Fernando Valley of the U.S.A. The San Fernando earthquake of February 9, 1971 in the San Fernado Valley Area, lying north-west of the city of Los Angeles (USA) produced a crack in the Van Norman Dam and threatened the breach of dam and possible flash flood but the local authorities realized the immediate danger and promptly dewatered the reservoir behind the dam and thus prevented the dam collapse and possible disastrous flooding of a densely built up area. Inspite of the prompt remedial measures adopted by local authorities the Sylmar Converter Station, one of the key elements in the electrical power transmission system of the Los Angles area could not be saved as it was severaly damaged.

Severe floods are also caused because of blocking of water flow of rivers due to rock blocks produced by severe tremors on the hillslopes facing the river valleys. Some times the blockade of the rivers is so immense that even the course of the river is changed. The 1950 earthquake of Assam, India, produced barrier in the Dihang river, the tributary of the Brahmputra river, due to accumulation of huge debris caused by landslides due to earth tremors and thus, caused severe floods in the upstream section. Similarly, the dam on Subansiri river broke in and resultant flash flood submerged an area of 7,770 square kilometres.

(8) Tasunami Waves

Undersea occurrencs of earthquake exceeding 7.5 on Richter scale very often generate strong waves, called as tsunami, which cause devastation in the coastal areas. The Pacific coasts are most valunerable to tsunami waves. The strong under sea earthquke with a magnitude of 9.3 on Richter, which occurred on December 26, 2004, in the Indian Ocean off Sumatra coast produced killer tsunami waves which claimed more than 250,000 human lives in the countries bordering Indian Ocean, mainly Indonesia, Thailand, India and Sri Lanka. Besides, huge property worth billions of US dollars was damaged. Detailed discussion on various aspects of tsunami disaster has been presented in the succeeding section 18.4 of this chapter.

EARTHQUAKE HAZARDS IN INDIA

India is frequently adversely affected by moderate to severe earthquakes in different parts of the country mainly the Himalayan regions, north Bihar, N.E. India,Gujarat etc. After first shocking earthquakes of Koyna in 1967 in Maharashtra, India has been severly rocked in August, 1988 (Darbhanga quake, 6.7), October 1991 (Uttarkashi, Uttarakhand, 6.6),September 1993 (Latur, Maharashtra, 6.3), May, 1997 (Jabalpur, M.P., 6.0), March, 1999 (Chamoli, Uttarakhand 6.8), January, 2001 (Bhuj, Gujarat, 8.1) etc. (table 18.9)

On the basis of magnitude of **damage risk** India is divided into five **damage risk zones** as follows :

(1) **Zone I of least damage risk** includes the places of some parts of Punjab and Haryana, plain areas of Uttar Pradesh, portions of plains of north Bihar and west Bengal, delta areas of Godavari, coastal plain areas of Maharashtra and Kerala, desert areas of Rajasthan and most areas of Gujarat except Kutch region.

(2) **Zone II of low damage risk** includes southern Punjab and Haryana, southern parts of plains of Uttar Pradesh, eastern Rajasthan, coastal districts of Orissa, Tamil Nadu etc.

(3) **Zone III of modernate damage risk** represents the areas of southern and south-eastern Rajasthan, most of Madhya Pradesh, Maharashtra and Karnataka, southern Bihar, Northern and north-western Orissa etc.

(4) **Zone of high damage risk** covers Jammu and Kashmir, Himachal Pradesh, northern Punjab, and Haryana, Delhi, western Uttar Pradesh, 'tarai' and 'bhabar' regions and Himalayan regions of Uttarakhand and Bihar, and Sikkim areas.

(5) **Zone of very high damage risk** includes parts of Jammu and Kashmir, some parts of Himachal Pradesh, Uttarakhand, extreme north Bihar, entire north-eastern India and Kutch region of Gujarat.

Though the plains of West Bengal comes under the zone of least damage risk but the devastating severe earthquake of Kolkata of 11 October, 1737 killing 300,000 people put a question mark against this concept. The zone of very high damage risk of Kutch region of Gujarat registered most devastating killer earthquake on January 26, 2001 (8.1 on Richter scale) in its seismic history of past 182 years killing 50,000 to 100,000 people. The towns of Bhuj, Anjar and Bhachau were flattened and razed to the ground.

Killer Bhuj Earthquake (2001)

While the people of India were celebrating the first republic day on January 26, 2001 of the new century in different parts of the country and the might of armed forces of the country was being displayed in New Delhi, the nature demonstrated its might by unleashing its immense energy in the form of a very severe earthquake which rocked Kutch region at 8.45 A.M. and shook the region for almost a minute. Within no time the villages and towns were flattened, high rise buildings collapsed, many villages and towns became heaps of debris, communication and power lines were completely disrupted, transport system was thrown out of gear and settlements became ruins. This was the second most devastating quake in the earthquake history of India after 1737 killer earthquake of Kolkata when 300,000 people were killed. The epicenter was located near Bhuj town (population 150,000). A moderate quake measuring 4.20 on Richter scale was registered on 24 December, 2000, the epicenter of this precursor quake was located only 22 km away from Bhuj town but no attention was paid to this precursor seismic event either by experts or govt. agencies. The Bhuj quake of Jan 26, 2001 was measured 6.9 on Richter scale by the Indian Meteorological Department (IMD) while the quake was measured 7.9 which was subsequently upgraded to 8.1 by the USA, France and China. National Geophysical Research Institute (NGRI) of India and Bhabha Aomic Research Center (BARC) also confirmed the American measurement (8.1). Acording to Indian Meteorological Department the main reason for the difference in the magnitude of the quake was the application of different methodologies for the measurement of seismic magnitude by different countries and organizations. It may be pointed out that the IMD uses body wave for the measurement of seismic magnitude while the USA uses shock waves for this. This severe devastating earthquake claimed the lives of 50,000 to100,000 people and adversely affected 5,00,000 people. Bhuj, Bhachau and Anjar towns were flattened, most of the buildings collapsed, 90, 60 and 50 per cent houses collapsed in Bhuj, Rajkot and Ahmedabad respectively.

If we look at the past seismic history of Gujarat, it appears that a severe earthquake occurs every 30 years e.g. Bhawnagar earthquake, 1872; Kutch earthquake, 1903; Dwarka earthquake, 1940; Broach earthquake, 1970 and Bhuj earthquake, 2001. Between 1845 and 1956 sixty six moderate earthquakes were registered in Kutch area but no one was killed,5 severe and one very severe earthquakes rocked the area. In fact, the sequence of destruction of Kutch began with the severe earthquake of June 19,1819 (7.1 on Richter scale) when 2000 people were killed, Bhuj town was destroyed, famous mosque of Ahmedabad was damaged, a 100 km long ridge known as Allah Bund (most of which is now in Sind of Pakistan, only 15 km ridge in India) was created.

The main reasons for the recent Bhuj quake of 2001 are : seafloor spreading of Indian Ocean at the rate of 5 cm per year, gradual northward movement of Indian plate and reactivated faults below the ground surface. Two major connecting faults have been located in Kutch region. A 200 km long and 100 km wide fault runs east-west between Bhuj and Ahmedabad. The second fault measuring 500 km in length and 100 km in width runs in north-south direction through Ahmedabad, Mehsana and Baroda and is known as Combay Graben. These subterranean faults intersect each other near Viramgam, Santhalpur and Radhampur towns and become the pivot of seismic events whenever these are activated due to plate movement.

MANAGEMENT OF EARTHQUARE DISASTER

The overall management of earthquake disaster involves the following aspects :

- risk assessment and analysis of earthquake hazards,
- preparation of earthquake vulnerability and risk zones maps,
- prediction of occurrence of earthquakes,
- earthquake disaster preparedness,
- search and rescure operation,
- relief operation after the occurrence of earthquake disaster,
- recovery of disaster-affected people from mental, economic and social problems,
- rehabilitations of displaced people, etc.

The advanced techniques of computing facility provided by advanced computers and analysis of mass dataset of seismic situation and geological formation provided by remote sensing technique have enabled the experts to prepare the maps of earthquake vulnerability and risk zones of varying magnitudes. For example, India has been divided into five earthquake risk zones (see preceding subsection, 'earthquake hazards in India'). All these help in making assessment of vulnerability of a region for seismic events and to initiate the necessary steps for the mitigation and prevention of adverse effects of seismic disasters. It may be mentioned that the occurrences of earthquakes cannot be precisely predicted because till now no suitable technique for earthquake prediction could be developed as the seismic events are sudden and very rapid on-set disasters and are related to the interior of the earth about which we do not know precisely. Though there are precursor tremors before the final on-set of earthquake disaster in near future but it is not precisely known as to when and where the earthquake would finally strike? Inspite of the complete uncertainty of earthquake prediction some precautionary measures, as mentioned below, should be taken to avoid and mitigate the disastrous effects of seismic events. Such measures are related to **pre-disaster phase** (see previous chapter) :

- to avoid the human settlements in the high earthquake risk zone,
- to follow earthquake resistant architectural designs for the construction of buildings,
- to use building materials of high quality and strength,
- to stop the construction of high rise buildings in earthquake-prone areas,
- to restrict the groundwater mining to avoid larger cavities below the ground surface which may weaken the foundations of buildings,
- to acquaint the people of earthquake-prone areas with safety measures in case of sudden ocurrence of an earthquake, so that they can immediately follow the safety rules in the case of calamity,
- to restrict urban growth in the hilly areas having high earthquake vulnerability risk,
- to avoid the construction of large dams and reservoirs in high seismic zones inorder to restrict the onset of reservoir-induced seismisity (RIS),
- to stop deforestation and massive quarrying in the high seismic zones of hill regions, etc.

As stated earlier, it is not the magnitude of earthquakes which kills people, rather it is the buildings which kill people. So, topmost priority should be given to follow approved standards of building construction. After the disastrous earthquake of Bhuj (Gujarat) in 2001, the central and all the state governments of India issued strict orders not to approve any plan for the construction of highrise buildings unless the provisions of all the safety measures as per standard codes of building construction have been taken care of but soon after the tragedy was over the people and officials became reluctant towards the implementation of building codes and rules.

Post-disaster measures of reduction of earthquake disaster includs three significant aspects as follows :.

(1) relief (R)

(2) recovery (R)

(3) rehabilitation (R)

There is immediate need of relief work after an earthquake has struck a locality. The relief operation includes search and rescue work; provision for temporary shelters of tin shades, tents, public buildings etc.; supply of clothes, food, safe drinking water and medicine; provisions for medical team; restoration of electricity, transport and communication etc. The first and foremost job is to search people who are trapped in the rubbles. This requires expert hands, sniffer dogs and some sophisticated elctronic devices. The extraction of people from the debris requires heavy machines (like cranes), buldozers etc. and suitable equipemts. The history of past events of earthquakes denotes the facts that generally the seismic events are followed by rainfall and therefore water proof tents and clothes are required to protect the victims from rain and cold. Such problems arose when an earthquake struck Pakistan Occupied Kashmir (POK) in October, 2005. The survivors of the quake faced acute problem of severe cold mainly in the hill areas and many surviviors died in the winter due to lack of heavy woolen garments and their exposure to extreme cold condition. Relief work should be undertaken according to the request and need of the concerned nation. No foreign aids should be rushed without the official request of the victim nation because unsolicited and unwanted relief supplies create confusion and complicate the problems instead of solving them. For example, the Dutch government sent a plane load of medicine and medical teams without the request of the government of Mexico, at the time of 1985 Mexico quake. This unsolicited, unneeded and unwanted medical team without local knowledge and language needed accommodation, transport, and interpreters and thus created further problem and consfusion in already troubled Mexico city. K. Nimpuno (1989) has commented on relief supplies to Mexico city during 1985 quake as follows :

"Despite all the damage Mexico city had more than enough medical resources; 20,400 physicians, 32,800 nurses, 500 ambulances, 110 hospitals, and 84 clinics. The foreign medical team had no role to fulfill. Some started vaccination compaigns without being asked and reinforced unfounded fears of epidemics'.

In fact, special search and rescue tools, communication equipments, heavy machines to remove debris, water pumps, cement and technicians are more important than drugs and doctors because 'the health dangers after disasters are predominantly environmental in character and not medical' (K. Nimpuno, 1989).

Rehabilitation of displaced earthquake victims needs permanent shelters to house those displaced persons whose houses have been either flattened or severely damaged. This requires huge monetary assistance which may not be sufficient from the resources of victim nation and hence financial assistance should also come from foreign countries, World Bank, and voluntary social organizations. It is heartening to note that besides government assiastance, the citizens of India liberally contrbitute to Prime Minister Relief Fund at the time of natural disasters. The rehabilitation of mentally injured people, destitudes and children who become orphans because of deaths of their parents and relatives in the disaster is another serious problem. Though a few individuals and social organizations come forward to adapt such children but this does not solve the problem. Many of them are left alone and uncared and hence only the government agencies can make arrangement for their rehabilitation and upkeep.

18.4 TSUNAMIS DISASTER

Tsunami disaster caused by killer waves in the oceans originating from a host of causative factors, undersea earthquake being the most significant factor, claims human lives and inflicts huge damage to human structures and properties in the coastal areas. Though the Pacific coasts are most vulnerable to tsunami disaster, but the recent tsunami disaster of Indian Ocean on December 26, 2004 proved to be the worst tsunami disaster of the recent past. This section includes discussion on the nature, causes, adverse effects and management of tsunami disaster.

Tsunamis : Nature and Characteristics

Tsunamis are high energy waves in the oceans generated by high magnitude earthquakes in the ocean floors (exceeding 7.5 on Richter scale), or by violent central volcanic eruptions or by massive landslides of coastal lands or of submerged continental shelves and slopes or in deep oceanic trnches. Tsunami is a Japanese word mening therby **harbour waves.** Tsunami consists of Japanese words tsu+nah+me = **'tsu'** (means harbour) and **'nami'** (means waves). Tsunamis are called as **'seismic sea waves'** because most of the tsunamis are generated by undersea seismic events (earthquakes). These are also called **high energy tidal waves.** Tsunami moves away from the center of origin with high speed and low crests across the ocean and is usually not noticed as the massive ocean waves move silently but assume destructive form as these travel through shallow waters of continental shelves and approach coastal waters and cause widespread devastation along the coastlines of low height and gentle slope.

Tsunamis are generally divided into the following two types :

(1) distant tsunami or deep sea tsunami; and

(2) local tsunami.

After being originated in the deep waters initial tsunamis are split in two e.g. distant tsunami and local tsunami. **Distant tsunami** moves out to the deep ocean (open ocean) while **local tsunami** travels towards the coasts. Thus, two tsunamis move in oppsoite directions. Distant or dep tsunamis travel much faster than local tsunamis but it is the local tsunami that causes destructioon in the coastal zones.

The following are the characteristic features of tsunami waves :

- Tsunamis are high energy sea waves caused by a host of causative factors but undersea earthquake event is the most potent factor.
- These are long waves having longer wavelengths exceeding 100 kilometers in the deep oceans but as these move coastward, their wavelengths decrese remarkably.
- After their origin tsunami wavs are split into two brances e.g. distant or deep tsunami, and local tsunami. These two tsunamis move in opposite directions i.e. local tsunamis move towards coastlines while distant tsunamis travel out to deep ocean. The speed of movement of these two waves depends on the depth of ocean water and hence varies as 'square root of water depth' of the ocean.
- As stated above, the speed of tsunami increases with increase in water depth and vice versa. Normally, distant tsunamis travel in the deep ocean with the speed of 500 to 1000 km/hour while the speed decreases remarkably as the local tsunamis approach the coast because the water depth also decreases substantially.
- The wavelength of distant tsunamis in the deep ocean is much longer exceeding 100 kilometers but the wavelength decreases as the local tsunamis approach the coasts.
- The wave height of distant tsunamis in the deep ocean is very low, say about a meter or so but as tsunamis approach the coasts the heights of both, distant and local tsunamis, increase phenomenally, some times exceeding 25 meters or so. In fact, as the depth of water on continental shelves decreases, the tsunami speed decreases but wave height increases. This is why tsunamis are not detectable in the deep ocean because of their very low wave height. This is the reason that ships travelling at the top of tsunamis in deap oceans do not feel the impact of tsunamis.
- The height of water of tsunami waves above mean sea level (MSL) in the near shore zone is called **'tsunami run-up'.** This is the 'run-up' or wave amplitude that brings walls of water in the coastal zone and by sudden flooding of coasts these cause devastation.
- Tsunami waves do not break at the plunge line as do the surf currents rather tsunamis come over the beaches as walls of huge volume of water and invade the coastal zone far inland and the strong current and floating debris, may be called **floating missiles** or **tsunami missles,** cause havoc in the coastal areas by destroying human structures and killing people.

- The time lag between successive tsunami waves ranges between 20 to 40 minutes. In other words tsunami is not a **single wave phenomenon** but is a **multiple wave phenomenon.** So, one should not return to the beach after the first wave has returned back because after the sea recedes there may come a few more tsunamis after an interval of 20-40 minutes. Unlike normal sea waves, successive tsunami waves do not break nearing the beaches but enter the coastal zone further inland with full energy and force.
- Tsunamis, some times, generate peculiar waves called as '**edge waves** which move back and forth and parallel to the coasts'. These edge waves are responsible for the occurrences of successive waves with time interval of 20-40 minutes. This phenomenon further complicate the tsunamis and produces **tsunami syndrome** (named by Savdindra singh, 2006). The wave height or simply the crest of the first tsunami wave necessarily may not be highest, the next tsunami wave with further higher **run-up** (wave height) may invade the coast.
- The arrival of tsunamis in the coastal zone is heralded by sudden recession of sea water.
- The detection, tracking and monitoring of tsuamis in the deep sea is not possible because of low wave height. These can be detected only when these enter the shallow water zone of the continental shelves where tsunamis assume enormous wave crest but the time available to forewarn and to send an alarm of alert is very short. Generally, the time available is 20 to 30 minutes when tsunami hooters on the coast can work.
- When tsunamis are generated along a fault zone due to upthrusting of one side, they do not radiate in all directions, following circular paths rather they move in east-west or north-west directin depending on the orientation of fault. In the case of Sumatra tsunami of 2004, the direction of the rupture of fault measuring 1200 km was north-south and hence the waves moved in east-west direction.

Causes and Origin of Tsunamis

It may be emphasized at the very outset that tsunamis in ocean are not generated by the forces coming outside the earth's surface such as gravitational pull of the moon and the sun rather these are produced by the forces coming out from within the earth such as tectonic movements which cause undersea earthquakes, volcanic eruptions, undersea landslides, faulting and downthusting etc., which become plausible causes of tsunamis. In fact, tsunamis are produced due to large-scale displacement of immense volume of sea water due to sudden tectonic disturbances in the sea floor. The changes and disturbances in sea floor are produced by a host of causative factors such as faulting in the sea floor, slumping and massive undersea landslides, sliding of large blocks of ice near the fiord coasts, avalanches, submarine volcanic eruptions, undersea seismic events etc. Thus, the following factors may be identified as tsunami producing factors :

- **Undersea powerful earthquake** event exceeding 7.5 magnitude on Richter scale. The tsunami of December, 26, 2004 in the Indian Ocean is a fine example of earthquake-generated tsunamis.
- **Undersea massive landslides** caused by sudden tectonic movements displace seawater upward which generates tsunamis.
- **Collision of convergent destructive plates** and subduction of relatively heavier plate below relatively lighter plate results in upthrusting of plate margins which causes sudden upward movement of immense volume of seawater resulting into the genesis of tsunamis. The dimension and magnitude of tsunamis in terms of force and energy depend upon the nature of rapture of plate margins and upthrusting thereof. The Sumatra tsunami of 2004 in the Indian Ocean was the result of such rupture and upthrusting and consequqnt occurrence of **tsunamigenic earthquake** of the magnitude of 9.3 on Richter scale.
- **Explosive volcanic eruptions** in the sea floor or on islands also generate powerful tsunami waves. The violent eruption of Krakatoa volcano in the year 1883 generated a powerful 120-foot (36 meters) high tsunami which claimed the lives of 36,000 people of Java and Sumatra.

If we examine the causes of genesis of tsunamis as discussed above it becomes evident that it is the tectonic movements and disturbances in the sea floor which are the pivatal cause of tsunamis because undersea earthquakes, undersea volcanic eruptions, underwater massive landslides etc., which are sources of the origin of tsunamis, are themselves the results of sudden tectonic movements such as faulting, rupture of seabeds, collision of converging plates and upthrusting. The expedition team of the experts of several disciplines including tsunami modellers, funded by the **Discovery Channel,** spent 17 days on board the ship **Performer** in May, 2005 to find out the exact cause of the origin of tsunami of 2004 in the Indian Ocean. The team found that the half of the 2400 km long fault in the Indian Ocean ruptured on December 26, 2004 due to subduction of Indo-Australian plate below Burma plate, a part of Asia plate. This sudden collision of two plates and rupture of southern half (1200 km) of the said fault lifted the seafloor by 10 to 12 meters and thus displaced 200 trillion tonnes of seawater which generated strong tsunami initially travelling at the speed of 500 miles (800 km) per hour.

The moment the plates collide and rupture, the ruptured part of the plate is displaced and lifted upward, the potential energy of displacement is changed into kinetic energy which generates horizontal movement of water in the form of waves, which are called tsunamis. Thus, the waves so generated from the place of displacement move outward in all directions. Initially, the wave height is generally a meter or two but as the tsunami waves approach shallow waters of continental shelves, their height (amplitude) increases but the speed decreases. Such high crest tsunami waves become disastrous when they strike the coasts of very low height and gentle gradient. This is the reason that the breadh of continental shelves control the energy and ferocity of tsunamis. Much of the energy of tsunamis is dissiplated on broader and shallow continental shelves and hence tsunamis become less destructive than the coasts having narrow continental shelves.

Chronology of Tsunami Events

Though to the most of Indians the word tsunami was alien before December 26, 2004 when the powerful tsunami struck the coasts of southern India and played a dreadful drama by killing thousands of people and destroying properties worth billions of rupees, but the people of the Pacific coasts knew the killer tsunami long before. Though tsunami is a natural phenomenon and is associated with the earth's tectonic activities and hence is a part of the dynamics of oceans and might have occurred since the oceans came into existence but due to lack of proper recording of tsunamis, the accurate chronological description is not possible. It is believed that the evidences of earliest known tsunamis are available since 1400 B.C. when a powerful and violent volcanic eruption in the Santorin island generated high energy tsunami in the eastern Mediterranean Sea which washed out the ancient Minoan civilization. In fact, we get systematic description of tsunami tragedy from the 19th century. The following is probable chronological order of important tsunami disasters :

1400 B.C. : A powerful tsunami, triggered by a violent volcanic eruption in the island Santorin in the eastern Mediterranean sea, washed out and completely obliterated the ancient Minoan civilization.

1775 (Portugal) : The great tsunamis caused by the Lisbon earthquake (Portugal) of the year **1775** generated about 12-m high sea waves which damaged most parts of Lisbon city and killed 30,000 to 60,000 people

1819 (India) : The Kutch earthquake (Gujarat, India) of June 6, **1819** generated strong tsunamis which submerged the coastal areas. The land area measuring 24 km in length was raised upward because of tectonic movements. This raised land area was called the **Allah's Bund** (Bund created by the God).

1868 (Peru) : A dreadful tsunami having 21m wave height adversely affected African and Peru coasts. The tsunami wave was so powerful that it carried ships 5 km inland.

1881, December 31 (India) : The first tsunami event on the eastern coasts of India was recorded on December 31, **1881** when an earthquake measuring 7.5 on Richter scale caused by the subduction of plate to the east of Nicobar Island triggered tsunami waves.

1847 (India) : 31 October, Great Nicobar and Car Nicobar.

1883, August 27 (Indonesia) : A severe earthquake caused by violent volcanic eruption in Krakatoa, located between Java and Sumatra on August 27, 1883 generated furious tsunami waves ranging between 30 to 40m in height (average being 120 feet or 36.5m) which devastated the coasts of Java and Sumatra and killed 36,000 persons and rendered lacs of people homeless.

1896, June 15 (Japan) : nearly 27,000 people were killed on the east coast of Japan.

1933 (Japan) : A powerful tsunami caused by tsunamigenic quake took off in the Japan Trench with a wave height of 27m. The tsunami took 10 hours to reach Sans Fransisco on the west coast of USA and 20 hours to reach Chile on the west coast of South America.

1941 (India) : A tsunami triggered by tsunamigenic earthquake in the Andman islands was noted on June 26, 1941 but could not be recorded due to military disturbances and political uncertainty created by Japanese attack on Andmans in ·1941. The earthquake was measured 8.5 magnitude on Richter scale.

1945 (India) : A 11.8-meter tsunami hit the Gulf of Combay, Gujarat, in November 1945 but no records are available.

1946 (N.A.) : The Aleutian tsunami (April 1, 1946), generated by Aleutian earthquake of the magnitude of 7.8 on Richter scale, with a height of 35 meters killed many people in Alaska and Hawaiian coastal areas.

1952 (Kamchatka) : The Kamchatka tsunami was generated on November 4, 1952 due to tsunamigenic quake of the magnitude of 8.2. This tsunami with a height of 15 meters was a Pacific-wide phenomenon.

1957 (Alaska) : An earthquake of the magnitude of 8.3 on Richter scale generated a Pacific-wide tsunami with a height of 16m, known as Aleutian tsunami, on March 9, 1957. This tsunami adversely affected Hawaii islands.

1960 (Chile) : A strong earthquake of the magnitude of 8.6 generated a Pacific-wide tsunami, known as Chilean tsunami, on May 22, 1960 and claimed 2,300 human lives in Chile alone.

1964 (Alaska) : A strong tsunamigenic quake of the magnitude of 8.4 on Richter scale, generated 15 m high wave known as Alaskan tsunami on March 28, 1964 and killed more than 120 people in Alaska.

1975 (Philippines) : The tsunamigenic Moro Gulf quake generated 5-meter high tsunami waves on August 16, 1975 which killed 3000 people, injured 8,000 persons and rendered 12,000 families homeless.

1976, August 23, Philippines : Nearly 8,000 people were killed.

1992 (Nicaragua) : September 2, 1992, maximum wave height 10 meters, human casualties 170 in Nicaragua.

1992 (Flores Island) : December 12, 1992, in Flores Island of East Indes, S.W. Pacific Ocean, maximum wave height 26 meters, human casualties more than 1,000.

1993 (Japan) : July 12, 1993 Okushiri, Japan, maximum wave height 31 meters, human casualties 239.

1993 (Papua New Guinea) : July 12, 1993, S.W. Pacific Ocean, East Indes, maximum wave height 15 meters, human deaths more than 2,200.

1994 (East Java) : June 2, 1994, maximum wave height 14m, human casulalties 238.

1995 : October 9, 1995, Jalisco (Japan), maximum wave height 11 meters, least human casualty (only one).

1996 (Sulawesi Island) : January 1, 1996, Sulawesi Island of East Indes in S.W. Pacific Ocean, maximum wave height 3.4 meters, human casualties 9.

1996 (Irian Jaya) : February 17, 1996, near Papua New Guinea in S.W. Pacific Ocean, maximum wave height 7.7 meters, human deaths 161.

1996 (Peru) : February 21, 1996, north coast of Peru, maximum wave height 5 meters, human casualties 12.

1994 (Mindoro Island) : November 14, 1994, Mindoro Island of Philippines, maximum wave height of 7m, human casualties 49.

1998 (Papua New Guinea) : July 17, 1998, a maderate intensity (7.0 on Richter scale) submarine earthquake and resultant massive submarine landslides generated 30 m high tsunami which claimed thousands of human lives along the coasts of lagoon.

2004 (South and South East Asia) : December 26, 2004, A powerful earthquake of the magnitude of 9.3 on Richter scale, off the coast of Sumatra with its epicenter at **Simeulue** in the Indian Ocean occurred at 00:58:53 (GMT), 7:58:53 (Indonesian Local Time) or 6.28 a.m. (Indian Standard Time, IST) and generated a powerful tsunami with a wavelength of 160 km and initial speed of 960 km/hr. The deep oceanic earthquake was caused due to sudden subduction of **Indian plate** below **Burma plate** upto 20 meters in a boundary line of 1200 km or even more. This tectonic movement caused

10-12 m rise in the oceanic bed which suddenly displaced immense volume of water causing killer tsunami. This earthquake was largest (highest on Richter scale) since 1950 and the 4th largest since 1900 A.D. The Andman and Nicobar group of islands were only 128 km (80 miles) away from the epicenter (Simeulue) and the east coasts of India were about 1920 km (1200 miles) away from the epicenter. The furious tsunami with a height of about 10 m adversely affected 12 countries bordering the Indian Ocean, worst affected areas included Tamil Nadu coast and and Andman-Nicobar Islands of India, Sri Lanka, Indonesia and Thailand. The strong tsunami took about 3 hours to strike Tamil Nadu coast. The killer tsunami claimed more than 250,000 human lives in the affected countries wherein Indonesia, Sri Lanka and India stood 1st, 2nd, and 3rd in the number of human casulalties. Detailed discussion on **Sumatra tsunami** will be presented in the succeeding subsection.

2006 (Java) : 17 July, 204 km S.W. of Java, undersea earthquakes of 7.7 and 6.1 magnitude generated 2.5 to 3.0 m high tsunami killing more than 600 people of Java.

2009 (Samoa) : 30 Sept., wave height-4-6m, death foll-> 100, under sea earthquake, manitude = 8 to 8.3.

2011 (Japan) : 11 March, 130 km off the coast of Sendai City, undersea earthquake of 8.9 magnitude generated 10m high tsunami killing more than 10,000 people, shattered nuclear Power Plants in Fukushima resulting into leakage of dangerous radioactive radiation.

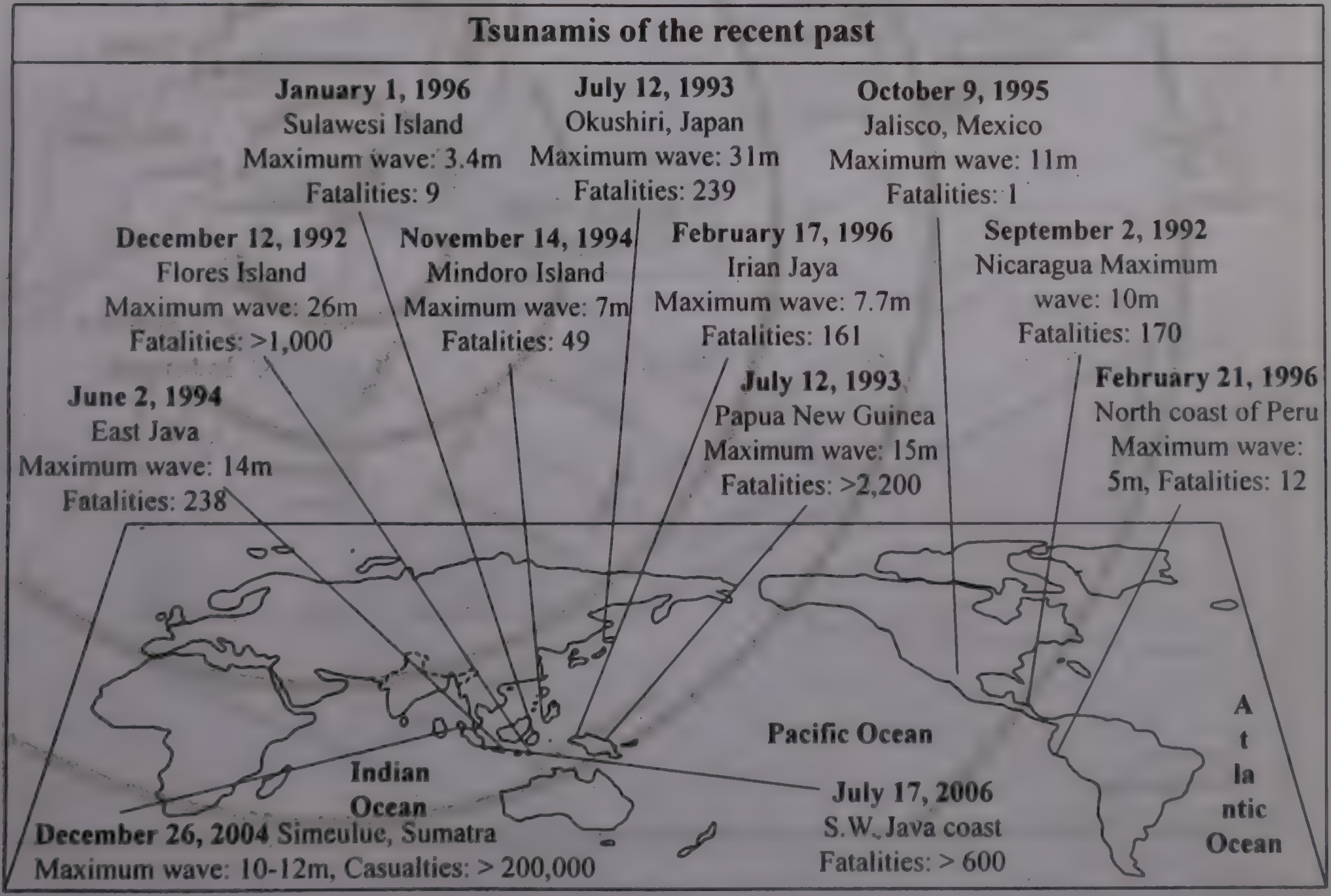

Tsunamis of the recent past
January 1, 1996
Sulawesi Island
Maximum wave: 3.4m
Fatalities: 9
July 12, 1993
Okushiri, Japan
Maximum wave: 31m
Fatalities: 239
October 9, 1995
Jalisco, Mexico
Maximum wave: 11m
Fatalities: 1
December 12, 1992
Flores Island
Maximum wave: 26m
Fatalities: >1,000
November 14, 1994
Mindoro Island
Maximum wave: 7m
Fatalities: 49
February 17, 1996
Irian Jaya
Maximum wave: 7.7m
Fatalities: 161
September 2, 1992
Nicaragua Maximum wave: 10m
Fatalities: 170
June 2, 1994
East Java
Maximum wave: 14m
Fatalities: 238
July 12, 1993
Papua New Guinea
Maximum wave: 15m
Fatalities: >2,200
February 21, 1996
North coast of Peru
Maximum wave: 5m, Fatalities: 12
Pacific Ocean
Indian Ocean
Atlantic Ocean
July 17, 2006
S.W. Java coast
Fatalities: > 600
December 26, 2004 Simeulue, Sumatra
Maximum wave: 10-12m, Casualties: > 200,000

Fig. 18.4 : Major tsunamis from 1990 to 2004.

Source : Frontline, 2005.

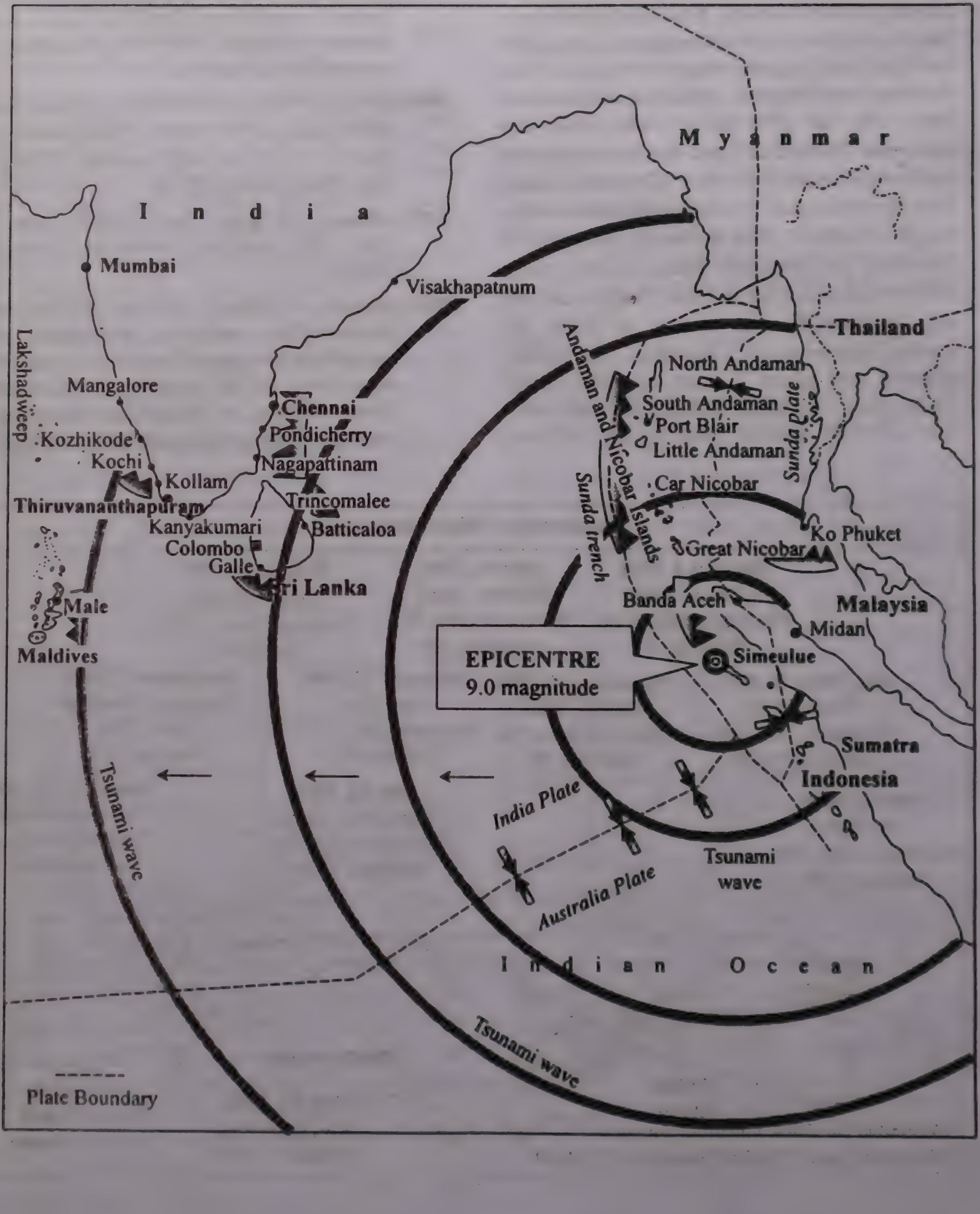

Myanmar
India
Mumbai
Visakhapatnum
Thailand
Lakshadweep
Mangalore
Kozhikode
Kochi
Kollam
Thiruvananthapuram
Kanyakumari
Colombo
Galle
Sri Lanka
Chennai
Pondicherry
Nagapattinam
Trincomalee
Batticaloa
Male
Maldives
Andaman and Nicobar Islands
North Andaman
South Andaman
Port Blair
Little Andaman
Car Nicobar
Great Nicobar
Sunda plate
Sunda trench
Ko Phuket
Malaysia
Banda Aceh
Midan
EPICENTRE
9.0 magnitude
Simeulue
Sumatra
Indonesia
India Plate
Australia Plate
Tsunami wave
Tsunami wave
Tsunami wave
Indian Ocean
Plate Boundary

Fig. 18.5 : Sumatra tsunami of 2004 and adversely affected locations. Source : Outlook, January, 2005.

Tsunamis occur mostly in the Pacific Ocean wherein 86 per cent of the total tsunami occurrences are the products of tsunamigenic undersea earthquakes. In fact, the Pacific rim is the most favoured tsunamigenic region because this region represents the collision (and hence subduction) zone of continental and oceanic plates and hence is the tectoncially most active area and generates most of world's earthquakes, most of the Pacific tsunamis are the result of undersea earthquakes. Though tsunamis are comparatively rare phenomena in the Indian Ocean but not unprecedented natural events. The decadal average number of tsunami ocurrences worldover is 57 whereas the decade 1990's alone accounted for as many as 82 tsunamis. The last major 10 tsunamis, leaving 2004 Sumatra tsunami, claimd about 4,000 human lives whereas December, 26, 2004 Sumatra tsunami of Indian Ocean claimed more than 250,000 human lives in 12 countires bordering the Indian Ocean.Significant tsunamis since 1990 have been shown on fig. 18.4.

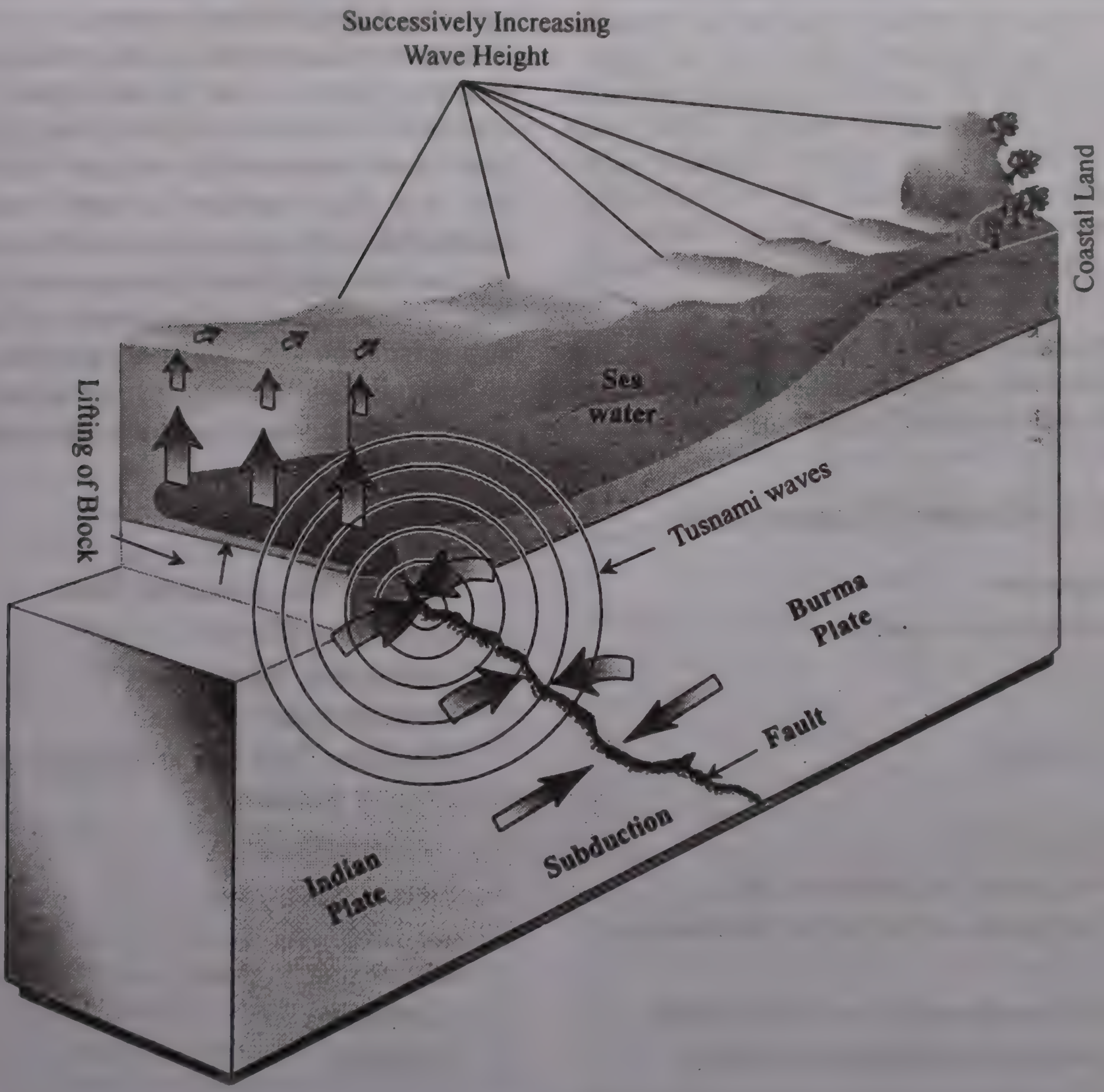


Fig. 18.6 : Genesis of Sumatra tsunami of December 2004 in the Indian Ocean. Source : Outlook, January, 2005

Adverse Effects of Tsunami Disaster

The adverse effects of tsunami attacks are many folds ranging from human casualties to loss of properties including cattle, crops, fishing, tourism, transport systems, communication systems; destruction of beaches, shifting of locations of small islands, deposition of sands on coastal plains; destruction of marine ecological resouces mainly corals and fishes. Besides, the ferocity of powerful tsunamis also creates social problems such as mental stresses leading to physiological disorder and several types of diseases, such as epidemics, restlessness, fear psychosis etc. The following case study of Sumatra tsunami of December 26, 2004 clearly demonstrates the dimension of adverse impacts of strong tsunami.

Sumatra Tsunami (2004)

Powerful and deadly tsunami waves were generated in the Indian Ocean on December 26, 2004 due to occurrence of severe undersea earthquake measuring 9.3 on Richter scale with its epicenter at Simeuleu off the coast of Sumatra and 250 km (fig. 18.5) south-east of Banda Aceh town of Sumatra. These killer waves claimed more than 250,000 human lives of 12 countries bordering the Indian Ocean wherein Indonesia, Sri Lanka, India and Thailand were worst sufferers.

The Sumatra tsunami was generated by the tectonic activities i.e. subduction of Indo-Australian plate below the Burmese plate and consequent powerful undersea earthquake of the magnitude of 9.3 on Richter scale (fig. 18.6). The expedition team of the experts of several disciplines including tsunami modellers, funded by the Discovery Channel, spent 17 days on board the ship Performer in May 2005 to find out the exact cause of the orign of tsunami of 2004 in the Indian Ocean. The team explored a few possibilities ssuch as undersea landslides, faulting and thursting as probable causes of Sumatra tsunami and ultimately found that the half of the 2400-km long sbmarine fault in the Indian Ocean along the convergence zone of Indo-Australian and Asiatic plates ruptured on December 26, 2004 due to sudden subduction of Indian plate below Burmese plate, a part of Asia plate. This sudden collision of two convergent plates (fig. 18.6) and consequent rupture of the southern half (1200 km) of the said fault induced a high magnitude (9.3) earthquake with its epicentre at Simeuleu and lifted the sea floor by 10 to 12 meters and thus displaced 200 trillion tonnes of seawater which generated strong tsuanmi waves initially travelling at the speed of 500 miles (800 km) per hour in the deep sea and slowing down while reaching the coastal areas.

Vital Statistics of Sumatra Tsunami, 2004

➤ Day of occurrence : Sunday, December 26, 2004
➤ Time of undersea earthquake : GMT; 00 : 58 : 53
Indonesian local time; 7 : 58 : 53, Indian standard time : 6. 28 a.m.
➤ Epicenter of quake : Simeuleu, 250 km south-east of Banda Aceh town of Sumatra
➤ Location of epicenter : 3.3^0 N —95.78^0 E
➤ Magnitude of quake on Richter scale : 9.3
➤ Distance from quake epicenter to Andman and Nicobar : 80 miles (128 (km)
➤ Distance from quake epicenter to Bangkok : 1,260 km
➤ Distance from quake epicenter to Jakarta : 1,605 km
➤ Distance from quake epicenter to eastern Indian coast in Tamil Nadu : 2000 km
➤ Time taken by tsunami to reach east coast of Indin (a) Cuddalore : one and half hours after the quake i.e. 8.0 a.m.
(b) Chennai : at 8.40 a.m.
(c) Machilipattanam : 10.0 a.m.
➤ Time taken by tsunami to reach African coast : 6 hours from the event
➤ Average wave height at the east coast of India : 4 meters (4.1 m as recorded by Chennai port, whereas Ennore Port Trust recorded 3.5 m)

- Total number of countries affected by tsunami : 12
- Ranking of the earthquake : 4th since 1900; largest since 1950
- Total number of human casualties by 10 big tsunamis since 1990 : 4,000
- Total number of huamn casualties : more than 250,000

Indonesia, Sri Lanka, India and Thailand were worst affected by killer tsunami. More than 150,000 people were killed in Indonesia alone and Banda Aceh town of Sumatra was almost wiped out by 5m to 10 m high waves. A few villages of the western coast of Aceh province were washed out from the map while only a few houses could be saved. The bridges across the estuaries were washed out. The worst sufferer was Meulaboth town, only 150 km away from the epicenter (Semeuleu) of the quake as about 40,000 of its total population of 120,000 perished in the killer wave disaster.

Thialand, Tsunami waves hit the Thailand coasts at 8 a.m. local time. The Phuket and Phi Phi islands packed with tourists were attacked by 10m high waves, which claimed hundreds of human lives. The official sources put the total death toll at 5,291 but the actual figures might have been much more as thousands were reported missing. The foreign tourists enjoying at the beaches of Phuket island were caught by surprise and many of them were washed into the sea.

Sri Lanka, The killer tsunami waves first struck the eastern Barticaloa district at 8.45 a.m. local time and later ravaged 9 provinces of Jaffna, Trincomalee, Barticaloa, Amparai, Hambantota, Matara, Galle, Kulutara and Colombo and claimed lives of 30,882 people. More than 2.8 million people lost their homes and about one million were adversely affected. These figures were upto January 14, 2005 but the figures might have gone up. The unstopable waves measuring 8 to 11 feet in height destroyed expensive hotels, roads, bridges, rails, houses, other buildings, bus stations, vehicles in the northern, eastern and southern coastal rims of island nation. It was the absence of any tsunami warning system which was responsible for the destruction beyond imagination, otherwise there was ample time of 2 hours for safe evacuation if the people would have been timely forewarned.

Indian Scenario

The December 26, 2004 Sumatra tsunami hit the Indian coasts of Tamil Nadu, Andhra Pradesh, Orissa and Kerala but the Tamil Nadu coast was worst affected. Besides, Andman and Nicobar islands were devastated. Nagapattinam, Cuddalore and Kanyakumari districts of Tamil Nadu and Pondichery suffered heavily from the killer tsunami but Nagapattinam was the worst affected among the sunami hit coastal districts of south India. In the coastal rim of Nagapattinam 'the ferocity of the waves that hit Nagapattinam town was unimaginable. The waves lifted up mechanised trawlers, spun them around, and dumped them on the railway track there. One, weighing several tonnes, landed on the railway line to Nagore' (Frontline, 2005). The powerful tsunami waves entered Kalpakkam housing two nuclear reactor plants and killed 60 persons. The Mamallapuram temple was flooded by 6-foot tall wall of seawater, the groyne wall constructed for the protection of Mamallapuram beach was breached. The official records put death toll to 8,009 in Tamil Nadu.

The tsunami affected districts of Andhra Pradesh included Nellore, Krishna, East Godawari, West Godawari, Prakasam and Visakhapatnam where 107 persons were reported killed by tsunami waves. The Kollam and Alappugha districts of Kerala were badly affected by surging tsunami waves. As per official source 117 people were washed in the Arabian Sea. Andman and Nicobar islands suffered most from tsunami onslaught on December 26, 2004. The key islands, which were worst affected, include Car Nicobar (total population 40,000-50,000), Noncowarie Group of Islands (total population 21,000), Compbell Bay (total population 5,000), Little Andman (total population 21,000) and Chowra (total population 1800). Car Nicobar was worst affected as the island was almost flattened. The Indian Air Force base in Car Nicobar was washed away. Great damage was done to the tribals of the islands which included Great Andamanese, Onges, Jarawa, Sentinelese, Shompens, and Great Nicobarese. The Andman groups of islands were worst sufferers of the tsunami because of their nearest location to the center of epicenter (Simeuleu) of the earthquake and flattish nature of terrain. It may be mentioned that rich mangrove and corals minimised human causalties. The official sources put human deaths at 3,513 but unofficial sources recorded more than 10,000 human causalties.

Tsunami Diary of India (2004)

6. 28 a.m., earthquake of the magnitude of 9.3 on Richter scale occurs with its epicenter at Simeuleu about 250 km S.E. of Banda Aceh of Sumatra.

6.40 a.m., Indian Meteorological Department (IMD) knows about the occurrence of the earthquake but does not analyse the data because of computer develops defects.

7.30 a.m., Tsunami hits Car Nicobar, the Car Nicobar base of Indian Air Force informs the Air Force base at Tambaram about the quake. The Tambaram Air Force base informs the Defence Minister of India.

8.0 a.m, Tsunami waves hit Cuddalore, Chennai, and Machilipattanam.

8.31 a.m., IMD informs Crisis Management Group (CMG).

8.45 a.m., A fresh earthquake of 7.3 magnitude occurs near Andmans. Just after 15 minutes tsunami strikes India, Sri Lanka and Maldives.

8.56 a.m., Department of Science and Technology and Home Ministry are informed about the tsunami attack.

10.30 a.m., The Secretary of the Department of Ocean Development informs the Chief Secretary of India.

12 noon, Crisis Management Group meets to estimate damage and discusses rescue and relief work.

Table 18.13 : Devastation by Sumatra Tsunami in India, 2004

	Tamil Nadu	Kerala	Andhra Pradesh	Pondichery	Andman & Nicobar	Total
Population affected (in lakhs)	8.97	1.3	1.96	0.43	3.56	27.92
Number of villages affected	376	187	301	33	192	1,089
Human deaths	8,009	177	107	599	3,513	12,405
Orphaned children	289	3	6	39	143	480
Houses damaged	190,000	13,735	481	10,061	21,100	253,377
Cropped area affected (in hectares)	19,168	7,763	302	792	11,010	39,035
Boats damaged	52,638	10,882	12,189	6,678	1,401	83,788
Liverstock lost	1,653	—	86	2,685	27,331	31,755
Damage (Rs in crores)	4,528.66	2,371.02	342.67	466.0	3,836.56	11,544.91

Human deaths do not include 'missing' in the Andman and Nicobar Islands.

Source : 'Tsunami-A Report to the Nation', published by the Ministry of Information and Broadcasting, Govt. of India

JAVA TSUNAMI-2006

A localized tsunami with wave height from 2.5 to 3.0 m was generated due to the occurrence of shallow focus (10 km deep) earthquake of 7.7 magnitude on July 17, 2006 about 245 km south-west of Java of Indonesia in the Indian Ocean. The subduction of Australian plate under Sunda plate caused vertical uplift of the latter by 90 cm along 150 km long fault zone. This vertical uplift caused vertical displacement of seawater and generated tsunami waves moving in two directions i.e. (i) towards Java coast, and (ii) towards open sea in the direction of Christmas Island. Since the vertical displacement of sea water was only 0.9m, the resultant tsunami was localized and hence its energy was soon dissipated. This was the reason that this tsunami could not reach Indian coasts. This tsunami killed more than 600 people in S.W. Java coast and displaced 54,000 people.

JAPAN TSUNAMI, 2011

Date : March, 11, 2011; time : Japan time = 2.46 A. M., IST = 6.15 A. M.; undersea earth quake of 8.9 magnitude; epcenter 130 km off the coast of Sendai City near Lameng Village and 380 km north-east of Tokyo, at the depth of 10 km on sea bed; tsunami wave height 10m; more than 10,000 people killed; many cities like Miyako, Miyagi, Kesennuma were flattened; Sendai air port was inundated with heaps of cars, trucks, buses and mud deposits; aircrafts including fighter planes standing on air port were washed out by gushing tsunami waves; rotation speed of the earth increased by 16 microseconds; day length decreased by 1.6 microseconds; Honshu island was displaced by 2.4 m due to monstrous quake; earth rotational axis was displaced by 10 centimeters; 2100 km stretch of eastern coastlines having several villages, cities and towns were battered by killer tsunami; nuclear power plants in Fukushima severely damaged resulting into leakage of killer radiactive radiation; more than 5 lakh people in the radius of 20 km from Fukushima power plants were evacuated and shifted to safer places.

MANAGEMENT OF TSUNAMI DISASTER

As stated in the preceding chapter the management of any natural disaster includes two principal components such as (1) pre-disaster stage, and (2) post-disaster stage. The stages of reduction of tsunami disaster include the following :

1. Pre-tsunami disaster stage :

- identification and mapping of areas of tsunamigenic earthquakes.
- demarcation of coastal regulation zone (CRZ) and to make it free from human settlements and dense structures except a few important installations such as military bases.
- protection and conservation of natural line of protection from tsunami waves such as coastal dunes, beaches, mangroves, corals etc.
- installation of tsunami meters, tracking of undersea earthquakes and resultant tsunami waves.
- provisions for early tsunami warning system (TWS) and preparedness for timely evacuation of people living in the danger coastal zone to safer places.

(2) Post-tsunami disaster stage

The following steps should be taken after the tsunami has struck a particular locality of a country :

- rescue and evacuation of stranded alive people,
- immediate relief work,
- recovery, and
- rehabilitation.

(1) **Pre-tsunami disaster stage :** As stated earlier a tsunami is generally generated when the magnitude of undersea (submarine) earthquake is 7.5 or more on Richter scale. Such undersea earthquakes are called **tsunamigenic earthquakes.** The identification and preparation of maps of areas of potential tsunamigenic earthquakes is the first step under tsunami disaster reduction and mitigation programmes. The suduction zones of convergent plate boundaries along the rims of the Pacific Ocean are very high tsunamigenic potential areas. The western coastal zones of North and South Americas, and the eastern coastal rims of Asia and Australia are the danger zones of highest order and hence the people living in these areas should always be prepared to face tsunami tragedy. The subduction zone of Indo-Australian plates and Burmese plate part of Asia plate, are also vulnerable to tsunami events. The occurrence of December 26, 2004 Sumatra tsunami proved to be most disastrous in the past history of tsunami events as regards human casualties and property loss. Except the students of earth sciences and civil engineering and seismology, the general public, administrators, politicians etc. of India were not even acquainted with tsunami word. Now every nation having coasts should be in the state of preparedness to face the fury of tsunami.

Coastal zone regulation (CRZ) should be strictly enforced in order to save the humans from death traps of tsunami waves. In India coastal Regulation Zones were declared through government notification in 1991 wherein coastal and marine ecosystems are under continued threat. Such coastal zone natural ecosystems include coastal dunes, beaches, mangrove forests and coral reefs. The coasts as per 1991 notification have been divided into 4 zones as follows :

- **Zone I** includes most sensitive areas having mangroves and coral reefs. No development is allowed within 500 meters of the high tide water. It may be mentioned that coral reefs and mangroves are natural lines of protection from tidal surges and tsunami waves because these absorb a sizeable portion of wave energy and protect the humans from the fury of tidal surges and tsunami waves. These are variously called such as **natural line of defence, natural buffers, natural barriers** etc. The following three locations could suffer least destruction from December 26, 2004 tsunami onslaught because of rich natural buffers :

  (a) Pichavaram in Tamil Nadu

  (b) Muthupet in Tamil Nadu

  (c) Bhitarkhanika in Orissa

  Pichavaram and Muthupet in Tamil Nadu have dense cover of mangroves which were responsible for fewer human casualties and less property loss during 2004 tsunami waves. Bhitarkanika in Orissa has the second largest mangrove cover in India after Sunderbans mangroves of West Bengal. This is why villages around Bhitarkanika were least impacted by 2004 tsunami.

  Besides the above mentioned Indian locations, the Maldives comprised of 1,190 tiny islands rising on an average about one meter above sea level and having almost flat terrain have rich coral reefs which absorbed most of the energy of 2004 tsunami waves and restricted human casualties to only 85.

- **Zone II** includes the areas above 500 m distance line having towns and cities. Here, new constructions are permitted further landward from the already constructed buildings.
- **Zone III** comprises undeveloped areas and tourists centers. Permission to new constructions and development plans is granted on the basis of review of individual cases.
- **Zone IV** includes Andmans and Lakshadweep where a zone of 500 meters from the coast (high tide water) is fully protected and no construction and new development plan is allowed.

It may be mentioned that the rules for CRZ have been relaxed and diluted since 1991 through several amendments in 1994, 1997, 2000, 2001, 2002 and 2003 (June) and thus the island and coastal ecology has been systematically eroded by the government. For example, the limit of no-development zone in Andmans and Nicobars was relaxed from 200 m to 50 m on June 24, 2003. The inhabitants of Andmans paid the penalty of this government negligence and deliberate action on December 26, 2004 when the killer tsunami waves swallowed thousands of people of the islands and flattened most of human structures.

As per report of the US-based Earth Institute once mangrove forests covered 75 per cent of world's coastlines of tropical and subtropical nations but now only 50 per cent is covered with mangroves.

It is suggested that the Coastal Regulation Zone should be properly maintained to strengthen the ecological security of coastal areas. The fishing communities should be shifted beyond 200 meters, seawalls should be constructed along the 200 m line and mangroves should be developed all along the seawalls. Coastal dunes and swamps should not be reclaimed. New mangroves should be developed along tsunami vulernable coastlines, and exhisting mangroves should not be destroyed in the name of the development of tourism industry and agriculture.

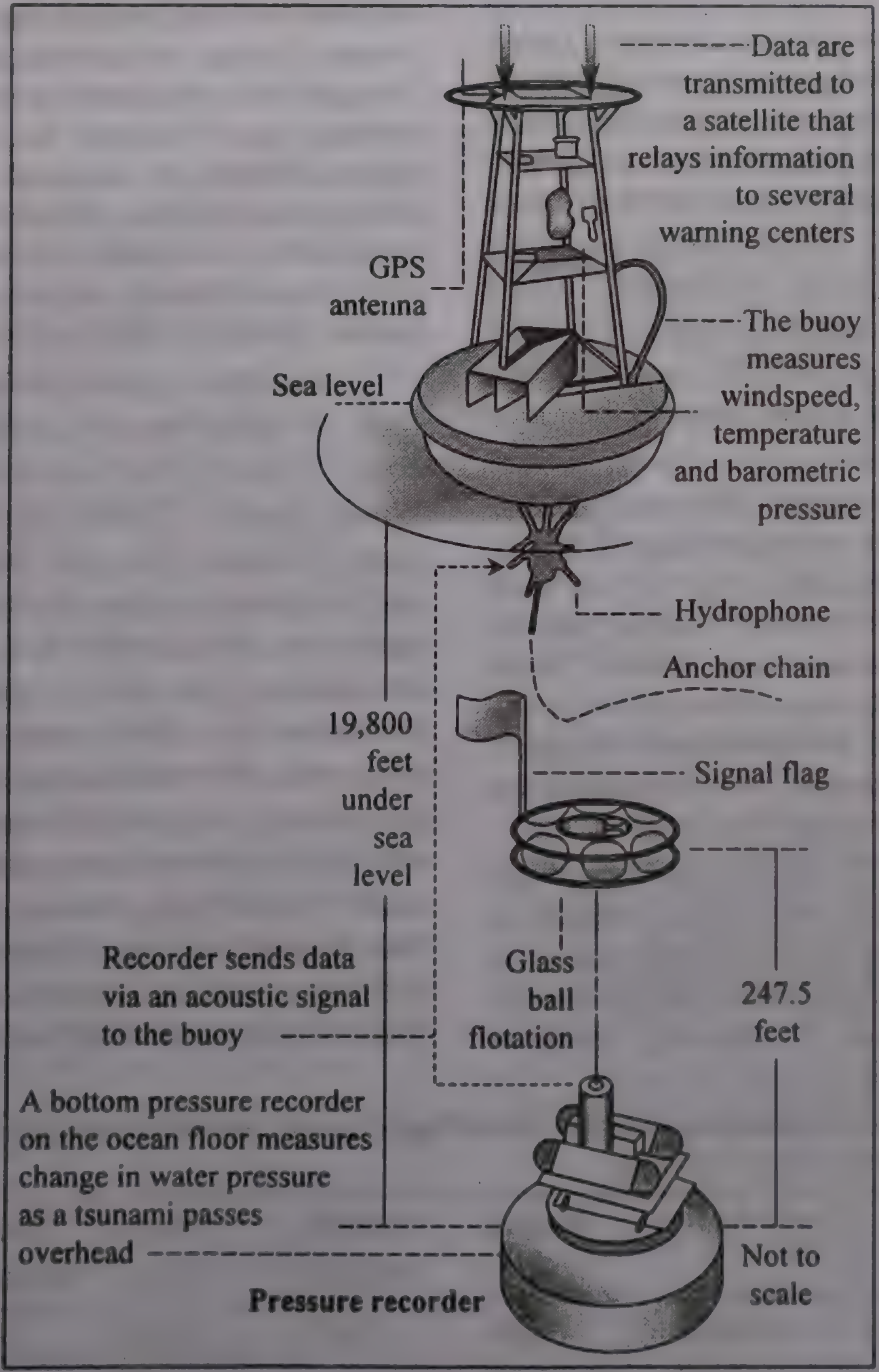
Tsunami warning system : The Pacific Tsunami Warming System (**PTWS**) was set up in the year 1948 with total membership of 26 countries around Pacific Ocean including Indonesia. The Tsunami Warning Centers (**TWC**) have been located in Alaska, Hawaii (USA) and Japan. Several tsunami meters (6 along the US Pacific coastlines, one near Chile and 14 off the Japanese coasts) have been installed along the Pacific coastlines. These tsunami meters detect, locate and determine the magnitude of tsunamigenic undersea earthquakes and send the data to the Pacific Tsunami Warning Centers (PT WC) located in Alaska and Hawaii which transmit information to Pacific Tsunami Warning System member countries (26 in number) within 3 to 14 hours. The tsunami meter consists of three major components as follows (fig. 18.7) :

(1) Pressure recorder (or deep sea sensors),

(2) Floating buoys, and

(3) Satellite.

The pressure recorders or deep sea sensors are placed at sea bottom (ocean floor) which measure changes in water pressure as a tsunami passes overhead. The recorders send the data through acounstic signal to floating buoys (placed at sea level). The buoys measure wind speed, temperature and barometric air pressure. The data so derived are transmitterd to satellites which relay information to tsunamis warning centers. These centers then issue warnings to member countries. It may be mentioned that the Pacific Tsunami Warning Center at Hawaii did know the genesis of Sumatra tsunami on December 26, 2004 but could not transmit to Indian Ocean Countries except Indonesia due to lack of the capability to receive tsunami advisories in these countries and to issue appropriate warnings. Hawaii PTWC did inform Indonesia and Australia which are members of PTWS but they ignored the warnings and did not inform India about tsunami waves.


Data are transmitted to a satellite that relays information to several warning centers
GPS antenna
Sea level
The buoy measures windspeed, temperature and barometric pressure
Hydrophone
Anchor chain
19,800 feet under sea level
Signal flag
Glass ball flotation
247.5 feet
Recorder sends data via an acoustic signal to the buoy
A bottom pressure recorder on the ocean floor measures change in water pressure as a tsunami passes overhead
Pressure recorder
Not to scale

SOURCE: National Oceanic and Atmospheric Administration (NOAA).

Fig. 18.7 : Tsunami warning system. source : National Oceanic and Atmospheric Administration (NOAA).

'Had any of the Indian Ocean nations been members of the Tsunami Warning System, they would have got the advisory and India would have had atleast three hours before the tsunami actually struck its coast to order evacuation or signal people to move to safety' (India Today, January, 2005) but timely warnings would have not saved Andmans and Nicobar Islands because 'the reaction time offered by the system (warning system) would be of the order of 5-10 minutes only. Practically it is as good as having received no warning' (V.K. Porwal, Hindu, 2005). But the east coasts of India would have been saved.

Now, efforts are on to set up Indian Ocean Tsunami Warning and Mitigation system (**IOTWS**). Under this plan Australia, India, Indonesia, Iran, Malaysia, Pakistan, and Tahiland would set up their National Tsunami Warning Systems (NTWS) which would detect tsunami in Indian Ocean and issue timely warnings of tsunami occurrence. Other countries would set up capability centers to receive tsunami advisories from the IOTWC and then issue warnings to the people of coastal areas of their own countries.

The **IOTWS** may install US-made DART (Deep-ocean Assessment and Reporting of Tsunamis) which has two components e.g. (i) sea level gauges, and (ii) deep sea pressure sensors. India is planning to create Tsunami and Storm Surge Warning System (**TSSWS**) at an estimated cost of Rs. 125 crores which would be operational by 2007. This system requires placing of 20-25 automated sea level gauges along the east and west coasts.

Besides, 10 to 12 DART-type deep sea pressure sensors and sea level buoys would be deployed to track tsunami and tidal surge waves on east and west coasts. The data from various sensors would automatically come to warning center at Hyderabad where the Indian National Center for Ocean Information Services (INCOIS), would handle the data. Visakhapatnam has also been suggested as ideal location of warning center.

(2) **Post-tsunami disaster stage** : The post-tsunami stage of disaster management includes three major steps, popularly known as **'three Rs'** after the tsunami has actually struck the coasts such as **relief work, recovery and rehabilitation.** On an average, there is spontaneous response for help if any disaster strikes a nation. The response to a disaster cuts across the language, religion and politics. The immediate response to December 26, 2004 tsunami devastation from several countries tells the truth of human feelings of helping the people in distress. Though India was itself severely attacked by 2004 tsunami, yet it helped the countries which were worst affected by tsunami fury like Sri Lanka, Indonesia, Thailand, Maldives etc. In fact, India stood tall as it initially did not accept foreign help rather urged foreign nations to help Indonesia, Sri Lanka, Thailand, Maldives etc.

Just after tsunami struck the eastern coasts of India, it started massive relief operation under the code - named relief operation as **'Operation Sea Waves'** wherein '20,000 men from armed forces, 40 ships of Indian Navy and Coast Guard, 34 aircrafts and 44 helicopters provided the logistics of the relief operations. While relief may not have been prompt or exacting, the fact is that by day 10 (from December 26, 2004) over 6 lakh people were evacuated, 605 relief camps set up to house 579,506 people and 2,142 medical teams were working round the clock to prevent any outbreak of epidemic and death' (India Today, January, 2005). It was said to be 'the biggest ever peace time relief operation'. The following table 18.14 dpicts the concerted action of India to undertake relief and restoration works :

Table 18. 14 : Relief and rehabilitation package under Rajiv Gandhi Rehabilitation Programme for tsunami hit states of India (Rs in crores).

	Tamil Nadu	Kerala	Andhra Pradesh	Pandi-chery	Andman & NIcobar	Total
(1) Relief and response	233.33	17.161	8.12	26.03	107.35	391.99
(2) Subsitence allowance	118.80	12.30	—	1.05	23.04	155.19
(3) Temporary shelters	90.00	17.39	0.31	6.04	99.10	212.84
(4) Permanent housing	650.00	50.00	2.30	50.00	—	752.30

(5) Relief equipment	54.00	26.00	12.60	1.95	9.75	104.30
(6) Infrastructure	161.15	44.01	10.35	6.61	305.97	528.09
(7) Agriculture & animal husbandry	32.35	3.52	1.16	0.80	261.66	299.49
(8) Assistance to fishermen	1007.56	78.98	35.16	63.14	15.01	1199.85
Total	2347.19	249.36	70.00	155.62	821.88	3644.05

Source : 'Tsunami : A Report to the Nation', published by Ministry of Information and Broadcasting, Govt. of India.

It may be mentioned that there was no dearth of men and materials for evacuation and relief work rather bureaucratic set up and mode of distribution of relief materials including food, clothes, shelters (tents) , medicines etc. was major impediment in executing relief operation in time. The rehabilitation programme is long-period task which may take a couple of years. The rehabilitation of 2004 tsunami victims in India was not complete even by June 2006. The fishing communities were the worst sufferers as they lost not only their houses but they also lost their means of livelihood such as fishing nets and boats. The restoration of such facilities requires huge monetary fund. The recovery from mental agony and fear is also a long-term process. The sea, once a source of livelihood of fishermen, turned to them as demon. This frightened the fishermen to venture into the sea for weeks and months from the dreadful tsunami event on December 26, 2004. The loss of kith and kins also upset many survivors who remained mentally stressed for several months. Thus, recovery from mental stress caused by any disaster is an uphill task.

18.5 LANDSLIDES HAZARDS AND DISASTERS

Landslides are natural as well as man-induced hazards when they occur in uninhabited area but they become disasters when they strike populated areas. Generally, hills and mountains and cliffed sea coasts are vulnerable to landslides of various sorts. The study of landslides hazards and disasters include discussion on meaning of landslides, causative factors, types of landslides, adverse effects of landslides and mitigation of landslides disaster.

Landslides : Meaning and Concepts

Disintegrated and fragmented rock materials due to mechanism of weathering processes (mechanical, chemical, biotic and biochemical) are called **rockwastes.** Generally, movement of rockwaste enblock down the hillslope is called **mass movement** of rockwaste or simply mass movement. 'Mass movement is the detachment and downslope transport of soil and rock material under the influence of gravity. The sliding or flowing of these materials is due to their position and to gravitational force, but mass movement is accelerated by the presence of water, ice and air'. It may be mentioned that generally all types of mss movements of rockwastes including soils and ice are collectively called as **landslides** which are variously classified on different bases *i.e.* direction of movement, type and rate of movement, nature of materials, presence or absence of lubricants etc. On an average, landslides (downslope movement of different types of debris enblock) are divided into five major categories e.g. fall, slide, topple, flows and lateral spreads. On the basis of nature of materials these are further subdivided into several types.

Factors of Landslides

Any sort of mass movement of weathered debirs leading to landslides with any rate whether on hillsope or valley side slope depends on the ratio between shearing forces (simply known as stress) and resistance of materials to shearing forces (*i.e.* shearing resistance of materials) as follows :

$$Fs = \frac{\text{strength or shearing resistance of materials}}{\text{magnitude of shearing forces}}$$

where Fs= factor of safety

When the quotient of shearing resistance of materials (simply strength of materials) and magnitude of shearing force i.e. safety factor (Fs) is less than 1.0 (*i.e.* when magnitude of shearing forces of hillslope or valley side slope exceeds the shearing resistance of materials resting on slopes) materials begin to move downslope and thus slides of weathered debris occurs. It is apparent that landslides may occur when either shearing forces increase or shearing resistance of materials decreases. It may be pointed out that either of the two processes (increase in stress and decrease in resistance of materials to stress) may operate or both the processes may operate together.

Based on this corollary D.J. Varnes (1978) classified the factors which control landslides in two broad categories and many subcategories : (1) factors which increase shearing forces (shear stress), and (2) factors which reduce resistance of materials to shear stress.

Recently, man has emerged as a significant factor of landslides in almost all of the environmental conditions. His activities (e.g. deforestation for commercial wood and increase in agricultural land; construction of roads; dams, reservoirs; urbanization on fragile hillslope; manipulation of rivers, coastal areas etc.) destabilize hillslopes as well as valley side slopes and accelerate the process of landslides and increase frequency and magnitude of different mechanisms thereof. Increased deforestation, cultivation on cleared hillslope, construction of roads and reservoirs in the Himalayas have made the mountain ecosystem more fragile and vulnerable to increased frequency and magnitude of different types of landslides.

Types of Landslides

A wide range of variations in terms of rate, and type of movements is noted in landslides in different places having varying environmental conditions. It is generally believed that landslides occur suddenly and instantaneously and hence all landslides cannot be witnessed by man. But in reality landslides have long preparatory period and there are certain **precursor events** which herald the occurrence of landslides but these are generally unnoticed. It may be mentioned that most of landslides occur in mountainous areas and hence it is not possible to notice the precursor events such as restlessness of animals, deserting of hives by bees etc. 'Hence if a landslide comes as a surprise to eyewitness, it would be more accurate to say that the observers failed to detect the phenomena which preceded the slide' (R.J. Chorley et. al, 1985). Landslides are generally classified on the basis of causative factors e.g. rate of movement, direction of movement, type of movement, lubricating substance e.g. water, ice etc.

The direction of landslides down the slope may be (i) vertical, (ii) lateral, and (iii) diagonal. Based on direction landslides may be divided into vertical movement, lateral movement and diagonal movement of rock waste. **Vertical movement (landsllides)** is further divided into (a) rocakfall, (b) collapse earthall. Lateral mass movement includes (a) block slide, (b) spread, (c) cambering, (d) sackung etc. Diagonal movement is divided into (a) soil creep, (b) rockcreep, (c) talus creep, (d) rockslide, (e) debris slide, (f) slump, (g) debris flow, (h) mud flow, (i) solifluction, (j) avalanche etc.

Based on the rate of movement and water content landslides are classified in 3 types :

(1) Large-scale rapid slide of rock waste. Water is needed as lubricating agent for such type of mass movement. Landslide is the typical example of this type.

(2) Slow flowage of rock waste and weathered debris. Partial saturation of rock debris is required for such mass movement and hence moderate quantity of water is needed as lubricating and stimulating agent. Rock creep, soil creep, solifluction etc. are typical examples of this type.

(3) Rapid flowage of weathered debris. Sufficient quantity of water is needed as lubricant. Earth flow, mud flow etc. are representatives of this type of landslides.

A generalized classification of landslides is presented as follows :

Table 18.15 : Classification of mass movement

1. **Very rapid movement**
   (no water is required)
   (i) Landslides
   (a) slump (b) debris slides
   (c) debris fall (d) rock fall
   (e) rock slides
2. **Slow movement (flowage or slide)**
   (little water is required)
   (i) Rock creep (ii) Soil creep
   (iii) Solifluction
3. **Rapid movement (flowage or slide)**
   (enough water is required)
   (i) Earthflow (ii) Mudflow
   (iii) Sheetwash

Table 18.16 : Classification of mass movement (R.J. Chorley, et. al. 1985)

1. **Vertical movement**
    - (A) **Fall** (of earth materials from very steep slopes like steep scarps and cliffs)
        - On the basis of materials
        - (a) rockfalls
        - (b) earthfalls (of alluvia, soils, colluvia)
        - (c) debrisfall (soils, alluvia, colluvia, vegetation and human structures)
        - (d) topple (rotational fall of rock slabs, or of earthen material)
    - (B) **Subsidence** (of the ground surface)
        - **Sinking**
        - (a) **collapse** (of roofs or underground caves or cavities or lava tubes)
        - (b) **settlement** (collapse of ground surface due to withdrawal of water, crude oil etc.)
2. **Lateral movement**
    - (A) **Slides** (sliding) (movement of materials along a horizontal fracture or interface between two rock strata of varying resistance e.g. sandstones-shales or limestones-shales)
        - (a) **block slide** (block glide) (downslope movement of a single large block of massive rock on such a surface which has been lubricated by water)
    - (B) **Spreading** (lateral displacement of a series of rock blocks (multiple blocks) or mud block downslope)
        - (a) **cambering** (draping of sedimentary units)
        - (b) **sackung** (lateral spreading away from anticlinal crests)
3. **Diagonal movement**
    - (A) **Creeping** (downslope movement of earthen materials at slow velocity)
        - (a) **soil creep** (movement of moistened soils downslope)
        - (b) **rock creep** (movement of rock upon rock)
        - (c) **talus creep** (rearrangement of scree and downslope movement)
    - (B) **Slide** (rapid rate of downslope movement of large quantities of debris of varying sizes) (on the basis of materials)
        - (a) **rock slides**
        - (b) **debris slides**
        - (c) **soil creep**
        - (d) **slumping** (movement of fine materials along a curved plane)
    - (C) **Flows** (dominant role of water, downslope transport of water-soaked fine debris)
        - (a) **earthflow**
        - (b) **slides**
        - (c) **mudflow**

18.17 : Simplified classification of mass movement (land slides)

1. **Fall**
    - (a) Rock fall
    - (b) Debris fall
    - (c) Earth fall
2. **Slides**
    - (a) **Slump**
        - (a) rock slump
        - (b) debris slump
        - (c) earth slump
    - (b) **Slides**
        - (a) rock slides
        - (b) debris slides
        - (c) earth slides

3. **Topples**
    (a) rock topples (b) debris topples (c) earth topples
4. **Flows**
    (a) Rock flow
    (b) Soil flow
    (i) debris flow (ii) earthflow
5. **Lateral spreads**
    (i) rock spreads (ii) debris spread (iii) earth spread

Landslide-prone Area

The most vulnerable regions from the standpoint of occurrences of landslides are the Himalayas mainly in Jammu and Kashmir, Uttarakhand, sub-Himalayan West Bengal (Darzeeling Himalyas), North-East Hill Region etc..

Human economic activities such as felling of trees for various commercial purposes but ultimately leading to deforestation and making the hilslope bare, road construction, urbanization, agriculture, building activities, construction of dams and reservoirs etc. destabilize hillslope and trigger the slides in already slide-prone areas of Uttarakhand Himalayas. There are frequent cases of landslides along the major roads connecting major human settlements and places of worships. The exposure of geomaterials all along the roads leading to holy places of Kedarnath, Badrinath, Gangotri, Yamunotri etc. denotes very weak formations which are slumped enmass due to heavy rainfall in general and cloud bursts in particular. The major causative factors of landslides in the Garhwal and Kumaun Himalayas include weak geological formations, active tectonism, slope instability, deforestation, building activity, unscientific farming, high intensity rainfall including cloud bursts etc.

Though numerous landslides of different varieties and varying magnitudes occur every year but not all of them are noticed and recorded. About 60 major landslides have been recorded since 1970 claiming more than 3500 human lives. The records of cloud bursts and landslides denote the fact that generally cloud bursts are succeeded by landslides of various sorts. The 1884 major slides of Nainital, the 1998 Malpa and Ukhimath (Rudhraprayag district) slides. etc. are a few examples of landslide disasters which inflicted heavy loss of human lives and property. In fact landslides are regular features of Uttarakhand Himalayan ecosystem and one cannot stop slides so long as human presence in the geologically and ecologically fragile Himalayan environment dominates hill ecosystem. One can only reduce the impact of landslide disaster. The recent **Vernavat landslides** and their impacts on the town of Uttarkashi located at the foot-hills of Vernavat mountain tell the awesome story of devastating impact of natural disaster on human society. All the devotees en route to holy Mansarover Kailash were camping during night (1998) in Malpa village located in the valley of Kali river when a massive landslide burried Malpa village and killed all the villagers and devotees.

The Darzeeling Himalaya is another landslide vulernable area of high magnitude. More than a dozen landslides of varying dimensions occur every year during monsoon rains.

Landslide Disaster Management

Like other natural hazards landslide disaster reduction and management involves two stages of action i.e. (1) pre-disaster stage, and (2) post-disaster stage. It may be mentioned that besides natural causative factors, landslides are also caused by human activities mostly deforestation, building activities, urbanization, quarrying and mining in landslide-prone hill areas. The foremost task in landslide management is to prepare landslide vulnerability maps on the basis of susceptibility of an area to landslides, landslide history of the region, frequency and recurrence interval of landslides, vulnerability index in terms of density of human settlements and population, economic activities, risk factor, loss of property etc. Such areas of high landslides vulnerability should be avoided for human settlements and building activities. Seismic events trigger more hazardous land slides. Such areas should be identified and demarcated and no development work should be allowed. Roads should not be constructed along hillslopes of weak formations. In nutshell efforts should be made not to undertake such economic activities which may destabilize fragile hillslopes. Removal of forest covers from hillslope should be immediately stopped and there should be massive reforestation of already denuded hillslopes with sincerity. The post-landslide disaster stage includes quick action of rescue of stranded alive people buried under thick cover of debris and to evacuate them to safer places Immediate medical help should be provided to survivors.

19

ATMOSPHERIC HAZARDS AND DISASTERS

Atmospheric extreme events, hazards and disasters represent unstable aspects of weather which include mainly atmospheric disturbances such as severe atmospheric storms (e.g. tropical cyclones, tornadoes, hailstorms, duststorms, snow storms, thunderstorms etc.). In fact, severe atmospheric storms are originated due to unequal spatial and temporal distribution of atmospheric energy and these storms exchange and transfer energy at global level. Since the atmospheric extreme events are caused by atmospheric processes which originate due to unequal distribution of energy within the atmosphere and hence these extreme weather events are also called as **exogeneous natural extreme events and hazards.** The atmospheric extreme weather events may be divided into two major groups, namely (1) **abnormal and infrequent events,** the mean duration of their occurrences ranges from milliseconds (such as lightning), minutes (tornadoes, thunderstorms, hailstorms etc.) to hours (e.g. dust storms, snowstorms, blizzards, flash floods), and (2) **cumulative atmospheric extreme weather events,** which prolong for days (such as tropical cyclones, arctic cyclones, floods, heat waves, cold waves, Nor' easters), weeks (regional floods), and even months (droughts).

Some of the extreme weather events leave instantaneous effects and cause human causalties, when they hit human beings (such as lightning), some of them have impacts both during the events and after the events such as floods, while some extreme events have long lasting and far-reaching impacts such as super cyclone of Orissa (India) in 1999, severe Gujarat and Rajasthan droughts during 1980s and 1990s. It may be mentioned that the frequency, recurrence interval, size and dimension, spatial and temporal characteristic features of atmospheric extreme events widely vary depending on the duration of such events. Tropical cyclones, tornadoes, regional floods and droughts are 4 most notorious atmospheric extreme events and disasters at global scales and these need detailed discussion.

(A) **Abnormal or infrequent hazards and disasters**

- (a) cyclonic disaster (tropical cyclones)
- (b) hurricane disaster (tropical cyclones)
- (c) tornado disaster
- (d) lightning disaster
- (e) hailstorm disaster

(B) **Cumulative atmospheric hazards and disasters**

- (a) flood disaster
- (b) drought disaster

(c) cold wave disaster

(d) heat wave disaster

19.1 TROPICAL CYCLONES DISASTERS

Tropical cyclone, representing a closed low pressure system generally having a diameter of about 650 kilometers, counterclockwise and clockwise air circulation in the northern and southern hemispheres respectively, energy power equivalent to more than 10,000 atomic bombs which were hurled at Nagasaki in Japan during World War II, is one of the most powerful, destructive, dangerous and deadly atmospheric storms on the planet earth. Tropical cyclones are differentally called in different parts of the globe such as **hurricanes** in the North Atlantic Ocean mainly in the Caribbean Sea and southeastern USA; **typhoons** in North Pacific Ocean, mainly in China Sea, eastern and southern coasts of China, **taifu** in Japan, Philippines and S.E. Asia; **cyclones** in Bangladesh and eastern coastal areas of India; and **willy willy** in Australia.

Tropical cyclones become more disastrous natural hazards because of their high wind speed of 180 to 400 kilometers per hour, high tidal surges, high rainfall intensity (highest recorded rainfall value exceed 2000 mm per day in Philippines), very low atmospheric pressures causing unusual rise in sea level, and their persistence for several days or say about one week. The total cumulative effects of high velocities of wind, torrential rainfall and transgression of sea water on to the coastal land become so enormous that the cyclones cause havoc in the affected areas and thus tremendous loss of human lives and property is the ultimate result of such atmosperhic deluge. The **'storm surge'** or **'tidal surge'** refers to unusual rise in seal-level caused by very low atmospheric pressure and the stress of the strong gusty winds on the sea surface. These storm surges or tidal surges, when coincide with high tide, are further intensified and after intruding into the coastal land cause widespread inundation of coastal areas and great damage of human live and property. The case histories of a few most powerful and disastrous tropical cyclones may unravel the magnitude of destructions wrought by these natural atmospheric disturbances.

1. Characteristics of Tropical Cyclones

Cyclones developed in the regions lying between the tropics of Capricorn and Cancer are called tropical cyclones which are not regular and uniform like extratropical or temperate cyclones. There are numerous forms of these cyclones which vary considerably in shape, size, velocity, and weather conditions. The weather conditions of low latitudes mainly rainfall regimes are largely controlled by tropical cyclones. They are characterized by the following salient features :

(1) Size of tropical cyclones varies considerably. On an average, their diameters range between 80 km and 300 km but some times they become so small that their diameter is restricted to 50 km or even less.

(2) They advance with varying velocities. Weak cyclones move at the speed of about 32 km per hour while hurricanes attain the velocity of 180 km per hour or more. Super cyclone attains the speed of 300 to 400 km/hr.

(3) Tropical cyclones become more vigorous and move with very high velocity over the oceans but become weak and feeble while moving over land areas and ultimately die out after reaching the interior portion of the continents. This is why these cyclones affect only the coastal areas of the continents (e.g. south and south-east coasts of the USA, Tamil Nadu, Orissa and West Bengal coasts of India, southern coastal regions of Bangladesh etc.).

(4) The center of the cyclone is characterized by extremely low pressure. Isobars are more or less circular but are fewer in number. This is why winds hurriedly rush up towards the center and attain gale velocity. The air pressure at the center sometimes becomes as low as 650 millimeters.

(5) Like temperate cyclones, tropical cyclones are not characterized by temperature variations in their different parts because they do not have different fronts (warm and cold fronts).

(6) There are no different rainfall cells in the tropical cyclones as is the case of temperate cyclones and hence each part of the cyclones yields rainfall.

(7) Tropical cyclones are not always mobile. Some times, they become stationary over a particular place for several days and yield heavy rainfall causing flood deluge and environmental disaster.

(8) The tracks of tropical cyclones vary considerably in different parts. Normally they move from east to west under the influence of trade winds. The general direction is westerly upto 15^0 latitude

from the equator, poleward between 15^0-30^0 latitudes, and thereafter easterly. These cyclones weaken when they enter subtropical regions.

(9) Tropical cyclones are confined to a particular period of the year, mainly during summer season. The frequency and affected areas of tropical cyclones are far less than those of the temperate cyclones but damages done by them are much higher.

(10) Tropical cyclones become disastrous natural hazards because of their high wind speed of 180 to 400 km per hour, high tidal surges, high rainfall intensity (highest recorded rainfall value exceeded 2000 mm per day in Philippines), very low atmospheric pressure causing unusual rise in sea-level, and their persistence for several days or say about one week over a particular place.

2. Types of Tropical Cyclones

It may be pointed out that tropical cyclones are so varied in size, weather conditions and their general characteristics that no two cyclones are identical and therefore it becomes very difficult to classify them into certain categories. Generally, they are divided into 4 major types.

(1) Tropical disturbances or easterly waves

(2) Tropical depressions

(3) Tropical storms

(4) Hurricanes and typhoons

On the basis of intensity they are divided into two principal types and 4 subtypes.

(1) Weak cyclones
  (i) Tropical disturbances
  (ii) Tropical depressions
(2) Strong and furious cyclones
  (iii) Hurricanes and typhoones
  (iv) Tornadoes

(1) **Tropical disturbances** are migratory wave-like cyclones and are associated with easterly trade winds. They are also called **easterly waves.** Winds move towards center with low speed. Though they move in westerly direction under the influence of trade winds with low velocity but they are most extensive and widespread and influence the weather conditions of both tropical and subtropical areas. Most of the easterly waves develop between 5^0 and 20^0 north latitudes in the western parts of the oceans. Some times, they are so sluggish that they remain stationary over an area for several days. They are associated with heavy cumulus or cumulonimbus clouds which yield moderate to heavy rainfall with thunderstorms. Some times, the easterly waves are so greatly intensified that they develop into hurricanes. Generally, they develop in the Caribbean Sea and North Pacific Ocean during summer months.

(2) **Tropical depressions** are centres of low pressure surrounded by more than one closed isobars and are very small in size. Wind velocity around low pressure center ranges between 40-50 km per hour. Their direction and velocity are highly variable. Some times, they remain stationary at a place for several days. They usually develop in the vicinity of inter-tropical convergence (ITC) but seldom develop in the trade wind belt. Tropical depressions generally influence the weather conditions of India and north Australia during summers. After being originated in the Bay of Bengal these cyclones move in north-westerly and westerly directions and reach inner parts of India. Some times, they become so strong that they yield heavy downpour resulting into severe floods.

(3) **Tropical storms** are low pressure centres and are surrounded by closed isobars wherein winds move towards the centre with the velocity ranging between 40 to 120 km per hour. They frequently develop in the Bay of Bengal and Arabian Sea during summer season. They also develop in the Caribbean Sea and in the vicinity of Philippines. Many of these cyclones become violent and disastrous atmospheric hazards as they cause heavy rainfall and thus inundate lowlying areas of Bangladesh, delta region of West Bengal and coastal areas of Orissa, Andhra Pradesh and Tamil Nadu. The northern parts of Bay of Bengal mostly the Ganga Delta plains of West Bengal, India and Bangladesh very often suffer from frequent severe cyclonic storms and resultant storm surges (tidal waves) because of a combination of several natural conditions and phenomena such as astronomical tides, funneling coast configuration, low and flat terrains of coastal areas and frequent occurrence of severe cyclonic storms. The most disastrous cyclone, which hit the coastal low land of Benglaesh on November 12, 1970, claimed 3,00,000 human lives. Similarly, the deadly cyclone of 1737 claimed the lives of 3,00,000 people in the east coast of India. The disastrous cyclone of 1977 moving with a speed of 175 km per hour killed 55,000 people, destroyed the homes of 2,000,000 people

and ruined 1,200,000 hectares of agricultural crops and made most of the coastal land barren and wasteland because of deposition of thick layer of salt on the soils by storm surges in Andhra Pradesh. Super cyclone of Orissa of 1999 (Oct. 29-31) with wind velocity of more than 300 km per hour killed about 1,00,000 people (official figure, 10,000), washedout 200 villages, damaged standing crops of 1.75 million hectares and claimed loss of property worth 1,000 billion rupees in the coastal districts.

(4) **Hurricanes and Typhoons** : The extensive tropical cyclones surrounded by several closed isobars are called hurricanes in the USA and **typhoons** in China. They are also called **willy willy** in Australia, **cyclones** in Indian Ocean, **'baguio'** in Philippines, **'taifu'** in Japan etc. Hurricanes are, in fact, most violent, most awesome, and most disastrous hazards of all the atmospheric disturbances. They move with average speed of more than 120 km per hour. Though hurricanes are most extensive and violent but their climatic importance is limited because of their fewer numbers and their occurrence in limited areas.

Besides, hurricanes are characterized by the following properties. The diameters range between 160 and 640 km. The size of hurricanes is usually small at their origin points near the equator but the size gradually increases away from the equator. The pressure at the centre ranges between 900 and 950 mb which is perhaps the lowest pressure of all the tropical cyclones. The pressure gradient between the centre and outer margin ranges from 10 mb to 55 mb. The areas of 6 to 48 sq km around the centre of hurricane is generally dry and rainless and winds are feeble. This is called **'cye of the cyclone'**. The waves caused in the oceans due to ferocity of hurricanes are called **hurricane waves** which are generally from 3 to 6 m in height. These storm surges inundate the coastal areas with immense volume of oceanic water and thus cause immense loss to human health and wealth. Hurricanes extend upto 12,000 m above the ocean surface. They last for many days and some times for more than a week.

3. Origin of Tropical Cyclones

There is no commonly acceptable viewpoint for the origin of tropical cyclones because the exact mechanism of the formation and development of these cyclones could not be properly understood as yet. According to the advocates of **frontal theory** all types of cyclones originate because of frontogenesis. Inspite of the absence of two contrasting air masses in the equatorial region fronts are formed due to meeting of land and sea winds. Initially, different fronts are formed but later they disappear. This **frontal concept** of the origin of tropical cyclone is no longer acceptable because tropical cyclones in no case are related to fronts. In fact, tropical cyclone is like a heat engine which is energised by the latent heat of condensation. On an average, tropical cyclones are formed due to the development of low pressure of thermal origin. They develop when the following requirements are fulfilled.

(1) There should be continuous supply of abundant warm and moist air. Without doubt tropical cyclones originate over warm oceans having surface temperature of 27^{0}C during summer season. (2) Higher value of coriolis force is required for the origin of these cyclones. It is apparent that tropical cyclones are practically absent in a belt of 5^0-8^0 wide on both sides of the equator where coriolis force is minimum. It means that cyclonic circulation of air is caused due to deflection in wind direction resulting from coriolis force. Majority of the tropical cyclones originate within a belt of 5^0-20^0 latitudes in the western parts of the oceans. (3) They are associated with inter-tropical convergence (ITC) which extends from 5^0 to 30^0 N latitudes during summer season. (4) Pre-existing weak tropical disturbances intensify and ultimately develop into high intensity violent tropical cyclones. (5) There should be anticyclonic circulation at the height of 9,000 to 15,000 m above the surface disturbance. The upper air anticyclonic circulation sucks the air from the ocean surface above and thus the upward movement of air is accelerated and low pressure centre at the surface is further intensified. (6) Tropical cyclones develop around small atmospheric vortices in the inter-tropical convergence zone (ITC).

The necessary conditions required for the formation of tropical cyclones (all types) may be summarized as follows :

- continuous supply of warm and moist air,
- suitable source of sensible and latent heat (of condensation),
- vertical air motion and convergence of air,
- powerful trigger mechanism in the form of intruding low pressure system at high altitude,

- warm water surface of oceans (having atleast 27^{0}C temperature) upto the depth of 60-70 meters,
- presence of pre-existing disturbances at lower altitude to be intensified and transformed into fully developed tropical cyclones,
- higher values of coriolis force,
- divergent circulation in upper troposphere,
- existence of small atmospheric vortices in the intertropical convergence zone,
- weak vertical wind shear etc.

4. Weather Conditions Associated With Tropical Cyclones

The arrival of tropical cyclones at a particular place is heralded by sudden increase in air temperature and wind velocity, marked decrease in air pressure, appearance of cirrus or cirrostratus clouds in the sky, and emergence of high waves in the oceans. The clouds are thickened and become cumulonimbus which yield heavy rains. The clouds are also associated with thunder and lightning. On an average, a single storm yields 100 to 250 mm of rainfall but if obstructed by relief barrier it may give as heavy rains as 750 to 1000 mm. The visibility becomes zero because the sky is overcast with thick and dark thunder clouds. Such destructive conditions persist for a few hours only. The arrival of the center or the eye of the cyclone is characterized by calm breezes, clear sky, rainless fine and settled weather, and low pressure at the centre. Such weather conditions do not persist for more than half an hour. The weather suddenly changes with the arrival of the rear portion of the cyclone as the sky again becomes overcast, wind direction changes, and pressure sharply goes up. There is heavy downpour with cloud thunder and lightning and storm becomes very severe and furious. This situation persists for several hours. Slowly and slowly the ferocity of cyclone starts declining and the weather becomes calm after the cyclone has passed off. The sea surface also becomes calm and clear weather sets in.

5. Distribution of Tropical Cyclones

Tropical cyclones mostly develop over the ocean surface between 5^0-20^0 latitudes in both the hemispheres and influence the weather of coastal areas of the continents. There are 6 major regions of tropical cyclones e.g. (1) West Indies, Gulf of Mexico, and Caribbean Sea, (2) Western North Pacific Ocean including Philippines Islands, China Sea, and Japanese Islands, (3) Arabian Sea and Bay of Bengal, (4) South Indian Ocean coastal regions off Madagascar (Malagasi), and (6) Western South Pacific Ocean, in the region of Samoa and Fiji Island and the east and north coasts of Australia.

North Atlantic Ocean : It may be pointed out that the occurrences of tropical cyclones are rhythmic in nature because they are restricted to a certain season of a year which varies from one region to the other region. On an average, about 7 cyclones develop every year in the southern and south-western parts of the Atalantic Ocean, most of which become hurricanes. They develop (i) in August and September around Cape Verde Island, (ii) between June and October to the north and east of West Indes and to the south of the Atalantic coast of the USA, (iii) from May to November in the north Caribbean sea, (iv) from June to October in the south Caribbean sea, and (v) from June to October in the Gulf of Mexico.

North Pacific Ocean : The cyclones after originating off the western coast of Mexico move north-westward and affect the weather of California. Some times, they also reach Hawaii Island. About 5 to 6 tropical cyclones develop each year between June and November and two of them gain hurricane intensity.

South-West North Pacific Ocean : Normally tropical cyclones develop in China Sea, off the coasts of Philippines Islands and South Japan between May and December. They have disastrous effects on the eastern coasts of China where they gain the ferocity of typhoons. About 12 typhoons develop every year.

South Pacific Ocean : Tropical cyclones develop to the east of Society Island (east of 180^0 longitude) during December-April and influence the weather of north-east coast of Australia.

North Indian Ocean : After originating in the Arabian Sea and Bay of Bengal tropical cyclones (also called as depressions) influence the weather conditions of India and Bangladesh on a large-scale between April and December.

South Indian Ocean : Cyclones originate off the coasts of Re Union, Madagascar, and Maritius islands between November and April.

6. Tracks of Tropical Cyclones

The tropical cyclones after their formation over warm water surfaces of the tropical oceans move westward in general between a zone of 5^0-20^0 latitudes in both the hemispheres under the influence of easterly trade winds but after reaching the western margins of the oceans and striking the continental coastal lands they curve north-westward and poleward. The equatorial warm ocean currents also help in the westward movement of tropical cyclones. After reaching 20^0-30^0 latitudes the tropical cyclones, if not exhausted and finished, move eastward under the influence of westerly winds. It may be mentioned that when the tropical storms strike the coast land, they start losing energy and dissipation as the source of required energy of latent heat of condensation, which is over the warm water surface of the tropical oceans, is cut off. Some times the tropical cyclones become stationary at a particular place for most part of their life cycle.

It may be remembered that the tracks followed by tropical cyclones vary considerably in different parts. Normally, they move from east to west under the influence of easterly trade winds and equatorial warm ocean currents. The general direction is westerly upto 15^0 latitude from the equator, poleward between 15^0-30^0 latitudes, and thereafter easterly (fig. 19.1)

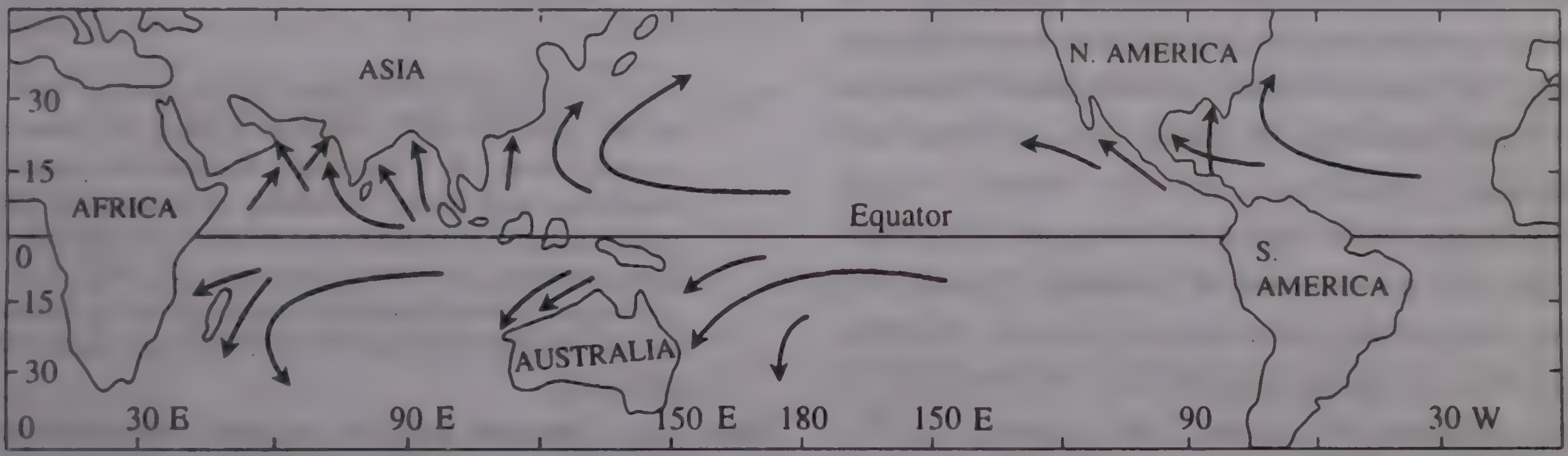


Fig. 19.1 : Tracks of Tropical Cyclones.

7. Adverse Effects of Tropical Cyclones

Tropical cyclones are very severe disastrous natural hazards which inflict heavy loss to human lives and property in terms of destruction of buildings, transport systems, water and power supply systems, disruption of communication system, destruction of standing agricultural crops, domestic and wild animals, natural vegetation, private and public institutions, etc. through damages caused by high velocity winds, floods and storm surges. Tables 19.1 to 19.3 depict the death toll of human life by tropical cyclones in different parts of the world.

It is now desirable to discuss the damages done by **hurricanes** in the USA, by **cyclones** in India, Myanmar and Bangladesh, by **typhoons** in China and Japan. and by **willy willy** separately but before that a general global picture of tropical cyclonic destruction is presented as follows :

Cyclone Nargis of May 2, 2008 caused following damages in Myanmar :

- the cyclone was of category 4 on severity scale.
- ravaged Irrawadi Delta including the cities of Yangon, Bogalay, Labutta and Pyapton.
- yielded total rainfall of 510 mm.

- killed more than 1,00,000 people.
- missing people = 43,000
- wind speed = 241 km/hr
- massive destruction to mangroves.

Destructions by tropical cyclones include loss of human lives and property in terms of destruction of buildings, transport systems, water and power supply systems, disruption of communication system, destruction of agricultural crops, domestic and wild animals, natural vegetation, private and public institutions and so on. The deadliest impacts of tropical cyclones and tornadoes are on human beings. There are 6 major regions in the world which are responsible for the origin of tropical cyclones *e.g.*, (i) West Indes, Gulf of Mexico, and Caribbean Sea; (ii) Western North Pacific Ocean including Philippines islands, China Sea and Japanese islands; (iii) Arabian Sea and Bay of Bengal; (iv) Eastern Pacific coastal region off Mexico and Central America; (v) South Indian Ocean, off Madagascar (Malagasi); and (iv) Western South Pacific Ocean, in the region of Samoa and Fiji Island and the east-north coast of Australia. It may be pointed out that the occurrences of tropical cyclones are rhythmic in nature because they are restricted to certain seasons of a year. The seasons of the occurrences of tropical cyclones vary from one region to the other region. For example, hurricanes mostly affect the U.S.A. between May and November wherein the maximum frequency is recorded in the end of summer and the beginning of autumn seasons.

Cyclone Aila

Initiation → May 23, 2009 in Central Bay of Bengal.

N.W. ward movement →May 24, 2009

Strikes West Bengal → May 25, 2009

Speed →110 km/hr

Duration →3 hours

Wave height →15 feet

Human lives lost →137 + 70 in Dunderbans

Livestock lost →71,196 in West Bengal 70,811 in Sunderbans

Crop area damaged → 2,90,000 ha in West Bengal 1,25,000 ha in Sunderbans

The following tables (19.1, 19.2 and 19.3) portray the death toll of human lives caused by tropical storms and local storms in different parts of the world :

Table 19.1 : Some noteworthy Indian tropical cyclonic disasters

Year	Human death	year	Human death
1737	300,000	1789	20,000
1833	50,000	1839	20,000
1864	50,000	1977	55,000
1990	598	1998	>1000
1999	>10,000		

Note : The intensity of 1990 Andhra cyclone was 25 times greater than the 1977 Andhra cyclone but human casualty could be contiained because of correct prediction and better warning systems but the property damage could not be stopped. On the other hand, inspite of timely warning of 1999 super cyclone of Orissa death toll of human beings could not be avoided because of inefficient government machinery.

Table 19.2 : Notable tropical cyclonic disasters in Bangladesh

Year	Human death	Year	Human death
1822	40,000	1876	100,000
1879	175,000	1960	5,149
1963	11,488	1970	300,000
1976	100,000	1985	11,000

Table 19.3 : Typhoon disasters in the Far East

Year	Country	Human deaths
1881	China	300,000
1923	Japan	250,000
1950	Japan	5,000

Hurricanes in the United States of America

The hurricanes are chronic disasters in the Gulf coastal and Atlantic coastal areas of the United States of America. Before attempting description of hurricanes onslaught in the USA, it is desirable to discuss the hurricane damage scale as devised by Saffir-Simpson popularly known as **Saffir-Simpson Hurricane Damage Scale** (table 19.4) wherein 5 point scale has been developed on the basis of size, intensity in terms of duration of occurrence in minutes, wind velocity in km/hour, height of storm surge and quantum of damage. The scale starts from a value of 1 for the weakest hurricanes of the shortest duration to the value of 5 for the strongest and most severe and hazardous hurricanes.

It may be mentioned that there is a practice in the USA to prepare a list of names for hurricanes in the beginning of a year and each hurricane is assigned a name e.g. hurricane **Katrina,** hurricane **Wilma** in the year 2005. The names of only those hurricanes are retained and are never used again to name new hurricanes, which attain the magnitude of 5 on Saffir-Simpson Hurricane Damage scale. Now India, China (typhoon **Carry**, typhoon **Betty**) and Japan also follow this practice.

Hurricanes very often strike the southern and the south-eastern coasts of the USA. Gulf coasts of Louisiana, Texas, Alabama and Florida are worst affected areas. The Galveston, Texas (U.S.A.) disaster of September 8, 1990 tells the story of devastation caused by hurricanes in the Gulf coastal region of the U.S.A. The terrible hurricanes generated a strong surge (tidal wave) which raced inland and killed 6,000 people mostly through drowning caused by inundation under 10 to 15 feet (3 to 4.5m) deep water and destroyed 3,000 houses. Flying planks and timbers under the force of strong gale winds also caused several deaths and damage to human structures.

Hurricane Katrina (2005) proved one of the most disastrous hurricanes in the US history of hurricanes. This killer hurricane inflicted heavy loss of human lives and property in New Orleans of Louisiana state. Similarly, **hurricane Wilma** (2005) greatly adversely affected Florida.

Table 19.4 : Saffir-Simpson hurricane damage scale

Scale number	Central pressure (mm)	Wind speed (km/hour)	Storm surge (meters)	Description
1	980	118-152	1.5	**minimum damage,** mainly to vegetation and mobile houses.
2	965-979	153-176	2.0-2.5	**moderate damage,** mainly uprooting and blowing of trees, roofs of buildings are damaged.
3	945-964	177-208	2.5-4.0	**extensive damage** to trees, mobile houses, roofs of buildings, structural damage to small buildings,
4	920-944	209-248	4.0-5.5	**extreme** [illegible]
5.	<920	>248	>5.5	**catastrophic,** windows glasspanes, roofs of houses and industrial buildings etc. are severely damaged.

Source : Summarized from J.E. Oliver and J.J. Hidore, 2003. It is apparent from table 19.4 that hurricanes are divided into 5 types based on the quantum of damage done by them, namely (1) hurricanes of minimum damage, (2) hurricanes of moderate damage, (3) hurricanes of extensive damage, (4) extreme hurricanes, and (5) catastrophic hurricanes.

It may be pointed out that Mississippi Delta Plains of the state of Louisiana (U.S.A.) have the equivalence of the Ganga Delta Plains of India and Bengladesh as regards the frequency and intensity of tropical cyclones but the damages mainly in the form of human casualties are far less in the former than in the latter because of more advanced and better warning systems. The **Audrey hurricane** of June, 1957 struck the Louisiana coast between New Orleans and Galveston. Though the storm was very severe as it smashed houses and floated them away, uprooted sealed concrete tombs and floated them 32 kilometres away from their resting places, but only 550 human deaths could be caused because of better warning systems and spontaneous response of people to the warning and predictions. In fact, the water level used to rise at the rate of 1.5 feet per hour. Thus most of the people had ample time to evacuate them to safer places before the water level forced by strong storm surge could reach its peak of 8 to 12 feet (2.4 to 3.6 m) above high tide water.

Table 19. 5 : Category-wise number of hurricanes in the USA from 1990 to 1996

	Saffir-Simpon damage scale (vide table 19.4)					
	1	2	3	4	5	Total
	Scale Number					
USA	58	36	47	15	2	158
Florida	17	16	17	6	1	57
Texas	12	9	9	6	0	36
Louisiana	8	5	8	3	1	25
North Carolina	10	4	10	1	0	25

Source : J.E. Oliver and J.J. Hidore, 2003.

Table 19.6 : Deadliest US Hurricanes

Location (name)	Year	Category Saffir-Simpon scale	Human deaths
TX (Galveston)	1900	4	8000 (may be 10,000 to 12,000)
FL (Lake Okeechobee)	1928	4	1836
FL (Keys), S. TX	1919	4	600
NE	1938	3	600
FL (Keys)	1935	5	408

FL = Florida, TX = Texas, NE = New England

Source : J.E. Oliver and J.J. Hidore, 2003.

Table 19.7 : Most Expensive US Hurricanes (property damage in US billions of dollars)

Name of hurricane	Year of occurrence	Damage cost
1. Andrew	1992	30.5
2. Hugo	1989	8.5
3. Agnes	1972	7.5

4. Betsy	1965	7.4
5. Camille	1969	6.1
6. Floyd	1999	6.0
7. Katrina	2005	damaged New Orleans
8. Wilma	2005	damaged Florida

Severe hurricanes cause havoc in the U.S.A. as regards the damages of property. 'In a ten-year period from 961 to 1971 property damage from United States hurricanes averaged some $ 440 million annually. Single hurricane in this period caused damage valued at $ 1.5 billion.' According to R.F. Abey (976) tornadoes cause the property loss of about 100 million US dollars and 150 human casualties per annum. 'Since 1950 every year in the U.S.A. there has been an average of 662 tornadoes, resulting in 114 deaths.' Efforts are being made to forecast the origin and travel paths of hurricanes and tornadoes in the U.S.A. on the basis of the study of synoptic situation combining seven elements viz. (i) convergence near the surface, (ii) mass divergence aloft, (iii) a buoyant airmass, (iv) wind shear in the vertical, (v) moist air mass in the lower layers, (vi) a trigger mechanism, and (vii) surface cyclogenesis. Attempts are also being made to develop effective devices of cloud seeding to decrease the intensity of hurricanes and tornadoes. Further more, scientists are trying to develop scientific methods to divert the paths of hurricanes and tornadoes to such areas which are not so important from the stand point of human population and economic loss.

Before 2005 there was an all time record of 19 hurricane storms in 1969 in the USA but the year 2005 witnessed a record number of 27 hurricanes out of which **Katrina** and **Wilma** proved to be most disastrous.

Cyclones in India and Bangladesh

Cyclonic hazards very often visit the eastern coastal areas of India and the southern coastal areas of Bangladesh. The disaster of the deadliest storm in the recorded history occurred on November 12, 1970 in the coastal lowland of Bangladesh. This Bay of Bengal disastrous cyclone tells the magnitude of environmental hazards in respect of its killer impact on the affected people as it caused as many as 300,000 deaths (some sources put the figure between 300,000 and 1,000,000 deaths in Bangladesh and West Bengal of India) wherein most of the deaths were caused by drowning in the storm surge of oceanic water (20 feet) on the land. The official record of Bangladesh presented the total loss as death of people-200,000, missing persons 50,000 to 100,000, cattle death-300,000, houses destroyed 40,000, crops losses of 63,000,000 US dollars, fishing boats destroyed-9,000 (offshore) and 90,000 (inland water).

The tropical cyclones coming from over the Bay of Bengal also become hazardous to the east coastal lands of India (West Bengal, Orissa, Andhra Pradesh and Tami Nadu). The deadliest hazardous cyclone struck the east coast in 1737 and claimed the lives of 300,000 people. Other disastrous cyclones occurred in 1977 (55,000 deaths), 1864 (50,000 deaths), 1839 (20,000 deaths), 1789 (20,000 deaths) etc., The November, 1977 cyclonic storm struck Andhra coast and generated three successive **'storm surges'** of which the biggest surge of 6 m height was recorded in the last. This deadly storm moved with a speed of 175 kilometers per hour. The biggest surge raced into the coastal low lying areas up to 20 kilometres inland and thus killed 55,000 inhabitants through drowning caused by sudden inundation, destroyed the homes of 2,000,000 people, ruined 1,200,000 hectares of agricultural crops and made most of the coastal land barren and wasteland because of deposition of thick layer of salt on the soils by storm surges. The saline land could be reclaimed only after three years.

The strongest and most notorious cyclone hit the Andhra coast on May, 9, 1990. It was 25 times stronger and more disastrous than the deadliest cyclone of November, 1977 (which also struck the Andhra coast as referred to above) but could claim the lives of only 598 people (official figure but the actual figure might have crossed 1,000 deaths). Besides killing 598 people, it adversely affected 3,000,000 people, rendered 3,00,000 people homeless, perished 90,000 cattle and caused loss of 1,000 crore rupees worth of property. Very low figure of human casualties (598 deaths) in comparison to the killer cyclone of 1977 (55,000 deaths) inspite of 25 times more intensity of May, 1990 cyclone than the latter was particularly because of the advance monitoring and prediction of the cyclone from the time of its formation in the Bay of Bengal off the southern coast of Tamil Nadu on May 5, 1990.

This cyclone is termed most notorious in the sense it shifted its course almost by 90 degree. But more than 100 direct warning systems and even dying INSAT-1B provided direct audio-broadcasts from meteorological stations in Chennai and Hyderabad and 6 cyclone detection radars fitted all along the coastline provided minute by minute information about the movement of incoming cyclone. Initially, the cyclone was moving westward and was expected to strike the southern coast of Tamil Nadu near Nagapattinam but after May 6 it suddenly shifted its course northwards and eventually hit the coastal districts of Andhra Pradesh and unleashed the devastating force of its fury on five districts viz. Krishna, Guntur, East Godawari, West Godawari and Visakhapatnam. It may be pointed out that the cyclone was so strong and enormous that some of the major towns of Krishna and Guntur districts such as Vijayawada, Machlipatnam, Pamarru, Guntur, Bapatia, Repalle and Tenali, which could not be affected by the deadliest 1977 cyclone and tidal wave, were also hit this time by the powerful storm surges (tidal waves) caused by gale winds with a speed of 220 to 250 kilometers per hour.

Gujarat coast was struck by a very powerful cyclonic storm with a velocity of more than 200 km per hour on Tuesday, June 9, 1998 and caused a surging tidal wave of 8 m height which transgressed into the coastal land and caused immense loss of property and human death unknown in the cyclonic history of Gujarat. The salt workers working in the salt pans in the Runn and the Little Runn areas of Kutch were washed away by high tidal waves. The storm was so powerful accompanied by heavy rainfall that human settlements were destroyed all the way from Surat and Amereli in Gujarat to Jalore and Jodhpur in Rajasthan. Mud built houses were flattened, power supply was snapped, trees were uprooted and carried away as missiles, and communication and vehicular traffic were completely disrupted. The storm caused more than 1000 human deaths and economic loss worth more than 100 billion rupees (unofficial estimates put the number of death between 5,000 and 10,000). Kandla port was greatly damaged.

SUPER CYCLONE OF ORISSA, 1999

The 29th October, 1999 proved a black and killer day for the inhabitants of the coastal region of Orissa (India) when the strongest cyclone in the cyclone history of India struck the Orissa coast and caused a havoc of mass destruction through its notorious acts from October, 29 to 31, 1999. Nearly one third of Orissa plunged into gloom and dispair. Prior to the final assault by this killer cyclone, a strong cyclone already knocked at the door of Orissa on October 18, 1999 with a velocity of 200 km per hour. This cyclone claimed the lives of 200 people, damaged 460 villages and adversely affected 500,000 people in Ganjam district. The people of Orissa were yet to recover from the trauma of this cyclone, the killer super cyclone hit the Orissa coast on October, 29. The successive phases of the formation and advancement of super cyclone may be outlined as follows : (1) **October 25 : A depression** was formed 500 km east of Portblair in Andman Sea, which started to move in N-W direction from the midnight and soon turned into a **deep depression.** (2) **October 26 :** The deep depression changed into a **cyclonic storm** by the morning of October 26 which was stationed about 350 km away from Portblair. The Indian Meteorological Department started to issue warning of advancing cyclonic storm. (3) **October 27 :** By the morning of October 27, this cyclonic storm changed to **severe cyclonic storm** and was positioned 750 km away from Paradeep port. It remained stationary for 6 hours at the distance of 600 km from Paradeep. (4) **October 28 :** Advancing towards north-west this severe cyclonic storm became a fully developed **supper cyclonic storm** and moved towards Paradeep with a velocity of 260 km per hour. (5) **October, 29 :** Indian Meteorological Department (IMD) issued an alarm of warning about the arrival of the super cyclone between Paradeep and Puri. Though the Govt. of Orissa was posted with this warning by 5.30 A.M. but this warning could not be conveyed to the general public due to lack of radio and television network.

Ultimately, the super cyclone entered Orissa on October, 29, 1999 and began to play its game of destruction in 10 coastal districts. Moving with a velocity of 300 km per hour the cyclone became stationary for 8 hours over this vast area. This disastrous cyclone generated 9 m high tidal surges which transgressed upto 15-20 km inside coastal region. Kendrapara, Jagatsinghpur, Balosore, Paradeep, Bhadrak and Khurda were worst affected. According to official sources more than ten thousand people were killed and 200 villages were completely washed out but the unofficial sources put human death toll at about hundred thousand. More than 6,000 people were killed in Jagatsinghpur alone. Several hundred thousand cattle perished and countless people were rendered homeless. The standing kharif crops over 1.75 million hectares were destroyed. The loss of property mounted to about 10,000 crore rupees (1,000 billion rupees). The severe super cyclonic storm resulted into the disruption of the supply of water and electricity. The communication system was thrown out of gear. Destruction and obstruction of roads and rails brought a grinding halt to rail and road transport which continued for weeks.

Cyclone Nargis (2008)

A disastrous cyclone of 5 magnitude on Simpson-Saffir damage scale hit Mynmar in the night of May 2, 2008. It ravaged Irrawadi Delta area including the cities of Yangon, Bagalay, Labutta, Pyapton etc. The following is the vital statistics of this notorious tropical cyclone :

- people killed > 100,000
- missing people > 43,000
- wind speed = 241 km/hour
- total rainfall = 510 mm

This cyclone did massive destruction of mangroves which are natural buffers against sea waves and storms. It may be mentioned that the intensity of tropical cyclone has doubled since 1950. Now scientists believe that global warming has been responsible for increase in frequency and severity of tropical cyclones.

8. Reduction and Management of Cyclonic Disaster

The reduction and management of tropical cyclonic disaster includes the following steps :

- Preparedness,
- Mitigation,
- Prevention,
- Relief work,
- Recovery, and
- Rehabilitation.

It may be mentioned that tropical cyclones are natural phenomena and the result of atmospheric oceanic dynamics and hence their occurrence cannot be prevented but their adverse effects can be minimized (mitigation). Efforts are being made in the USA to divert the tracks of hurricanes so that densely populated areas may escape from the paths of advancing hurricanes and thus the damages may be either prevented or atleast are kept to the minimum. Thus, the state of preparedness is the most significant step of pre-disaster stage for the management of cyclonic storm disaster.

The state of preparedness basicaly revolves around the mechanism of (ECWS) **early cyclone warning system**, and the establishment of **cyclone warning centres** (CWC) so that messages of advancing cyclones may be timely conveyed to the concerned area and the people may be evacuated to safer places in time. The cyclone warning system includes the following components :

- **Detection** of cyclones,
- **Identification of position** of cyclones in terms of vicinal location (in terms of latitudes and longitudes) and their distance from the area to be affected by the storms,
- **Tracking** of cyclones,
- **Means of detection**, location of position and tracking such as weather / meteorological satellites, doppler radars etc.,
- **Estimate of severity** of the storms on the basis of severity / damage scale from 1 (weak cyclone) to 5 (most severe cyclone i.e. super cyclone e.g. 1999 cyclone of Orissa, India),
- **Communication** of warning messages of advancing cyclones to the people and administrators of the concerned areas as well as central and state government authorities who may be concerned with the cyclone mitigation programmes. The warning message may be conveyed through electronic (television, radio network, fax, internet, telephones etc.) and print media (newspapers). The **cyclone warning system messages** (CWSM) include the hourly information about the location of storms, direction of movements, wind zones, wind velocity, probable dimension of storm surges mainly height, estimate of likely damage in terms of loss of human lives and property.

It may be mentioned that most of the developed countries, which are very often affected by tropical cyclonic storms and resultant storm surges have developed their own **cyclone warning system mechanism** (CWSM) such as the USA, Japan, China etc. China and India have also developed advanced system of detection, tracking and warning systems with the help of meteorological satellites, radars etc. Thus detection and tracking of tropical cyclonic storms are successfully done in many countries having tropical and subtropical coastal locations. The only problem is related to efficient mechanism of timely communication of warning messages in developing countries. Some times, the warning of hourly position of tropical storms is effectively and timely communicated but the damage is not contained. For example, the development of hurricane **Katrina** in the Caribbean Sea (2005) was timely detected and early warning was issued but the people of New Orleans, USA could not move to safer places and thus the loss of human lives and property could not be minimized.

India has also developed effective mechanism of detection and tracking of cyclones originating in the Bay of Bengal and the Arabian Sea through its meteosat-5, successive generations of INSAT, radars etc. All aspects of detection, tracking and cyclone warning system messages are exclusively handled by the Indian Meteorological Department (IMD) with its headquarters at New Delhi. There are more than 100 direct warning systems and half a dozen cyclone detection radars fitted all along the coastlines which provide minute by minute information about the movement of incoming cyclone.

It may be mentioned that the cyclone which struck the Andhra coast on May 9, 1990 was 25 times stronger and more disastrous than the deadiest cyclone of November, 1977 (which also struck Andhra coast and claimed 55,000 human lives) but could claim the lives of only 598 people (official figure but the actual figure crossed 1000 deaths) but the timely detection of shift in its trajectory and early warning enabled the people to move to safer places. Initially, the cyclone was moving westward and was expected to strike the southern coast of Tamil Nadu near Nagapattinam but after May 6 it suddenly shifted its course northwards and eventually hit the coastal districts of Andhra Pradesh and unleashed the devastating force of its fury. Though the loss of human lives was minimzed due to early warning and timely evacuation but property loss could not be contained.

Some times, the cyclonic storms are timely detected and warning messages are communicated to the government officials but the government machinery fails to inform the general public in time and thus the people are let loose to the fury of the storms. Such incident happened in the case of Orissa in 1999 when a powerful super cyclone with a wind velocity of 260 km per hour struck Orissa coast on October 29, 1999. The Indian satellites tracked the cyclone from October 25 when it was only a depression and was positioned 500 km east of Portblair in Andman Sea to October 28, 1999 when it assumed the form of super cyclonic storm of the severity scale of 5. The Indian Meteorological Department (IMD) issued an alarm of warning about the arrival of the super cyclone between Paradeep and Puri on October 30, 1999 and the Govt. of Orissa was posted with this warning by 5.30 a.m. but this warning could not be communicated to general public by the state government due to failure of radio network..

It is evident that communication of storm warning to the public and timely evacuation is the only effective measure of mitigation of cyclonic disasters.

The post-disaster stage of cyclnic storms disaster reduction includes rescue operation, quick and logical relief work with honesty and integrity, medical help, provision for temporary shelters, restoration of supply of water and electricity, restoration of communication system, effective and meaningful rehabilitation from temporary shelters to permanent houses, sufficient economic package to compensate property losses mainly cattle and agricultural loss in the case of farmer community and means of fishing for fishing community etc.

19.2 THUNDERSTORMS DIASTER

1. Meaning and Concept

Thunderstorms, considered as tertiary atmospheric circulation, are local storms characterized by swift upward movement (updraft) of air and heavy precipitation including both rainfall, hailstorm and squall with cloud thunder and lightning. According to A.N. Strahler 'a thunderstorm is an intense local storm associated with large, dense cumulonimbus clouds in which there are very strong updraft of air.' 'Fundamentally, the thunderstorm is a thermodynamic machine in which the potential energy of latent heat of condensation and fusion in moist conditionally or convectively unstable air is rapidly converted into kinetic energy of violent vertical air currents with associated torrential rain, hail, gusty surface squall winds, lightning, and thunder……A thunderstorm is therefore an intense instability outbreak' (G.T. Trewartha, 1954). Because of heavy downpour associated with thunderstorms they are also called **cloud bursts** but the rainfall is of very short duration. Thunderstorms differ from cyclones in that the latter are almost circular in shape wherein winds blow from out side towards the center while the former is characterized by strong updraft of air. They are considered to be special case of convective mechanisms.

It is the cloud burst which causes flash floods in the plains and landslides in the hills. Uttarakhand of India is frequented with numerous cloud bursts each year which cause heavy loss of human lives and property.

2. Characteristics of Thunderstorms

The thunderstorms occurring in both tropical and temperate regions are characterized by the following salient features :

1. Thunderstorms are powerful local storms having swift updraft (upward movement) of air from the central point.
2. They are powerful thermodynamic machines wherein potential energy is transformed into kinetic energy through the input of latent heat of condensation and fusion. The resultant kinetic energy provides momentum to the storm.
3. Thunderstorm is a cellular type of vertical movement of moist air which comprises several convective cells.
4. Sometimes, a few thunderstorms coalesce and become powerful enormous storms, they are called **mesoscale convective complex.**
5. The thunderstorm having a single convective cell is not much powerful and hence is less violent but the storms having several convective cells become not only enormous convective machines but also become most disastrous.
6. The tropical thunderstorms are associated with heavy downpour, cloud thunder and lightning but in the middle latitudes they are also associated with hails, and squall besides heavy precipitation, cloud thunder and lightning but in the regions of dry climate there may be no precipitation.
7. The occurrence of thunderstorms in the humid tropics is almost a daily phenomenon but the frequency of their occurrence is more over land surfaces than over the ocean surfaces because of less intense convective mechanism over the oceans than over the continents.
8. Thunderstorms are short-duration local weather phenomena as the life cycle of these storms is completed within an hour or two but sometimes these storms last for a few hours.
9. On an average, about 16 million thunderstorms occur each year in tropical, subtropical, and middle-latitude regions and daily averages of occurrences of these storms have been reported to be 2000.
10. The strong thunderstorms associated with heavy precipitation through dense cumulonimbus clouds are characterized by strong downward movement of air (downdraft) which is called **downburst.**

3. Structure of Thunderstorms

The faully developed and strong thunderstorms comprise a few convective cells which may vary from 5 to 8 in number. These convective cells are characterized by strong updraft (also updraught) of air. Each cell covers a distance of a few kilometers and may last from one hour to 8-10 hours. The updraft of moist and unstable air is in the form of a chimney. The swift updraft of moist warm unstable air (chimney) allows the downdraft of relatively cool air as compensatory air movement. Each convective cell passes through three consecutive stages of its development and dissipation e.g. (1) **cumulus stage,** (2) **mature stage,** and (3) **dissipating stage.** The stages of life cycle of thunderstorm are described in the following subsection.

4. Conditions for Thunderstorm Development

Atmospheric instability, updraft of potentially unstable air, abundant supply of warm and moist air, thick clouds etc. are the factors which favour the development of thunderstorms. The upward movement of warm and moist air is prerequisite condition for the origin of thunderstorms. Surface heating through intense insolation causes convective mechanism resulting into updraft of air and atmospheric instability. This is why thunderstorms originate mainly during summer season, warm day of a season, and warm hours of a day. It appears that warm, moist and rising unstable air is the most important factor in the development of thunderstorms. This becomes possible when **normal lapse rate** of temperature is greater than **adiabatic rate** of temperature change. Besides convective mechanism, warm and moist winds also rise and become unstable due to orographic obstacles. The greater the instability of warm and moist air, the greater the intensity and duration of thunderstorms.

There must be greater thickness of clouds between **cloud base** (e.g level at which condensation and cloud formation begin) and **icing level** (i.e. the level at which water droplets change into ice particles). The higher the icing level above cloud base, the greater the thickness of clouds and thus the greater the intensity of convection. Since the icing level is at very low height in the middle latitudes, thunderstorms do not frequently develop there. On the other hand, thunderstorms are common features in the weather of low latitudes because of the higher height of icing and greater thickness of cloud cover.

The necessary favourable conditions for the origin and development of thunderstorms may be summarized as follows :

1. The atmospheric conditions should be in conditional or convective unstable state.
2. The normal lapse rate should be greater than adiabatic rate of temperature change.
3. There should be warm, moist and rising unstable air.
4. There should be enough supply of moisture from the ground surface to the air.
5. There should be greater thickness of cumulonimbus clouds between the condensation level (cloud base) and icing level.
6. Enough supply of latent heat of condensation and fusion which may transform potential energy into kinetic energy which provides strength to the storms.
7. There should be efficient trigger effects for causing and augmenting convective mechanisms. These may be effected through (i) insolational heating of ground surface and resultant rising convective air currents; (ii) forced ascent of moist air by mountain barriers; (iii) forced ascent of warm and moist air along cyclonic fronts (applicable in middle latitudes only) etc.

5. Stages of Thunderstorm Development

Like temperate cyclones, the origin and development of thunderstorms also passes through a life-cycle but unlike six-stage life-cycle of temperate cyclones, thunderstorms pass through only three-stage life-cycle as follows (fig. 19.2) :

(1) **Cumulus stage,** the first stage of the life cycle of a thunderstorm, is also called **youth stage,** when ground surface is intensely heated, the moist air coming in contact with heated ground surface is also heated, expands and rises upward as strong convective current losing temperature at the dry adiabatic lapse rate of 10°C per 1000 meters, reaches its condensation level and thus helps in the formation of clouds having precipitation particles. The updraft of moist air becomes stronger with greater wind speed exceeding 150-160 km per hour due to trigger effects as described in the previous subsection (4). Consequently, the cumulus clouds become thick comulonimbus clouds.

(2) **Mature stage** is the second stage of thunderstorm development characterized by both upward (updraft) and downward (downdraft) movement of air and occurrence of torrential rainfall from thick cumulonimbus clouds, maximum cloud thundering and lightning etc.

(3) **Dissipating stage** is the senile stage of thunderstorms. This final stage is characterized by downward movement of winds which laterally spread over the ground surface and stop vertical movement (updraft) of winds. Clouds spread in the sky in umbrella shape and become altostratus and cirrostratus resulting into dissipation of thunderstorm as these clouds are rainless. The downdraft of winds and end of updraft of winds causes the stability of the atmosphere and the energy is ultimately finished (fig. 19.2)

6. Classification of Thunderstorms

Thunderstorms are generally classified on the basis of their mode of origin and lifting factors and mechanisms.

(1) **Air mass thunderstorms**
  (i) heat (thermal) thunderstorms
  (ii) orographic thunderstorms
  (iii) advectional thunderstorms
(2) **Frontal thunderstorms**
  (i) warm front thunderstorms
  (ii) cold front thunderstorms

(1) **Thermal** or **local thunderstorms** originate due to intense heating of ground surface through insolation and resultant rising thermal convection currents. They are called local because they influence very limited area. In fact, heat thunderstorms are real thunderstorms which originate in the afternoon during summer season and die out by the evening. Heat thunderstorms are more common in the belt of **doldrum** because large amount of air moisture, high temperature and convergence of winds provide ideal conditions for their origin and development. Heat thunderstorms become stronger and more vigorous if the surface through which they travel is warmer, otherwise they are soon weakened if the surface is less warm. This is why they die out when they pass through water bodies (lakes, rivers, reservoirs etc.) because of no supply of heat from below. Heat thunderstorms also originate in the inner parts of the continents during summer season

in middle latitudes. Heat thunderstorms are difficult to be predicted because of their highly uncertain and variable behaviour.

(2) **Orographic thunderstorms** : When warm, moist and unstable air strikes a mountain barrier, it is forced to rise hurriedly along the hillslope. The latent heat of condensation (release of heat after condensation) accelerates the rate of upward movement of the air. This results in the formation of most active and strong thunderstorm which yields copious heavy rains. This is called **cloud burst rain.** The southwest Indian monsoon winds after strking the hillslopes produce strong thunderstorms which yield more than 10,000 mm of annual rainfall at Cherrapunji. Orographic thunderstorms are more extensive, widespread, and active than heat thunderstorms and thus their forecast is easy.

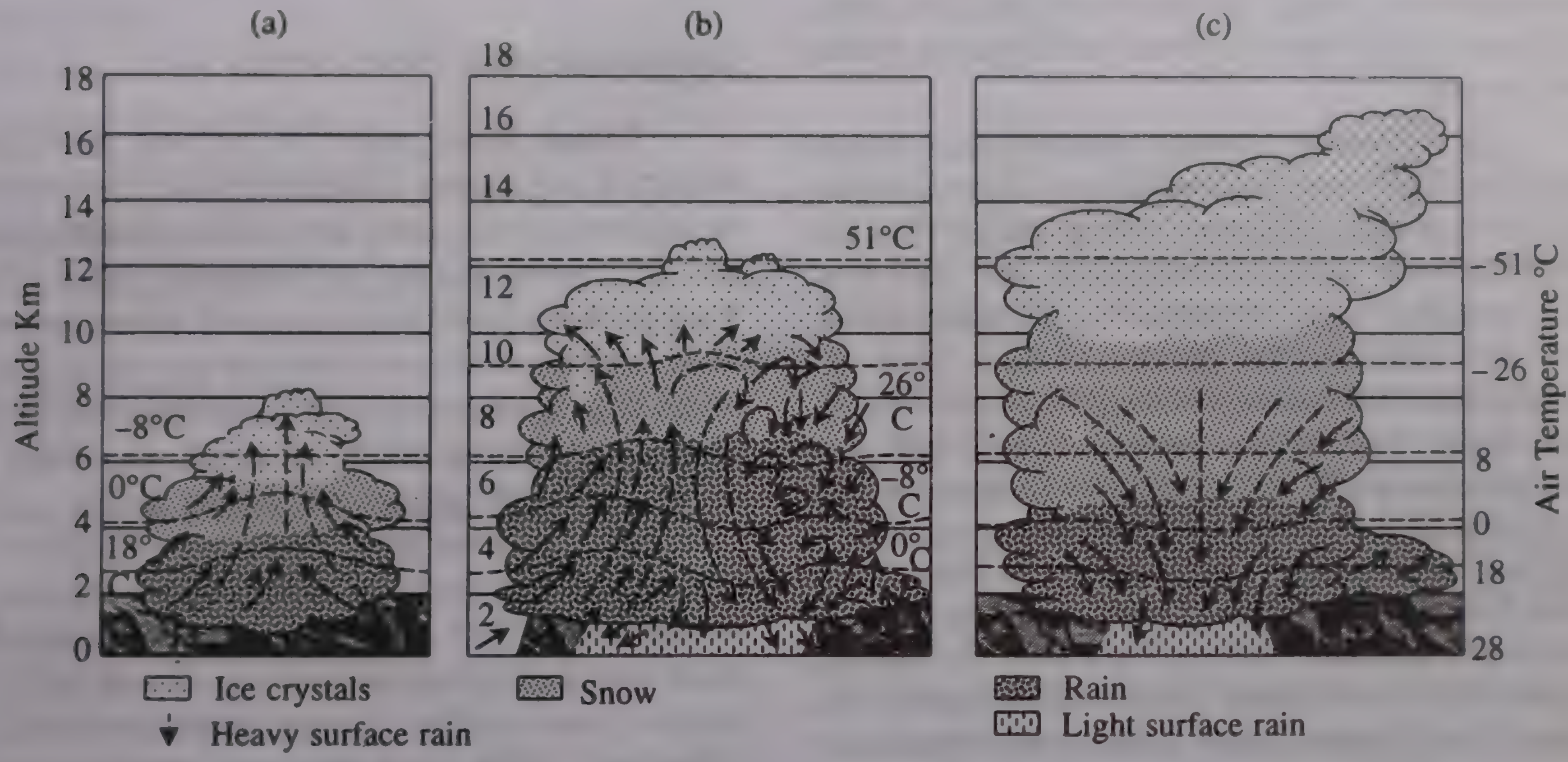


Fig. 19.2 : Development stages of a thunderstorm : (A) initial or cumulus stage marked by only updraughts, (B) mature stage marked by both updraughts and downdrughts, (C) dissipating stage marked by only downdraughts. Arrows indicate wind direction. Source : based on Byers and Braham; and Barry and Chorley, 2002.

Garhwal and Kumaun Himalayas of Uttarakhand are frequented by numerous orographic thunderstorms each year leading to cloud burst rain.

(3) **Advectional thunderstorms** are produced due to substantial increase in normal lapse rate of temperature and consequent upward movement of unstable air when a cold air underlies a warm air. Such thunderstorms develop during dark nights when the sky is overcast because the upper layers of the clouds are cooled due to loss of heat through radiation, with the result cool and dense air settles downward and pushes underlying warm and light air upward resulting into convective mechanism in the air.

(4) **Warm frontal thunderstorms** are produced when sea breezes are more humid and unstable. They are not significant because they are very weak storms. Cumulus clouds do not form because the air ascends slowly.

(5) **Cold front thunderstorms** develop along the cold front of temperate cyclones when cold and dense air pushes warm and moist air upward with great force. Since they are associated with temperate cyclones, they are easily predicted. Cold front thunderstorms may develop at any time of a day or in any season of a year because their origin is not related to the heating of the ground surface.

6. Thunderstorms and Weather

(i) **Rainfall** in thunderstorms, unlike tropical cyclones, is in the form of heavy downpour with greatest intensity of all other forms of precipitation but is of short duration because of two factors viz. (i) the air rises abruptly with great force due to which there is quick condensation and cloud formation, and (ii) there is abundant absolute humidity due to high rate of evaporation consequent upon very high temperature during summer season. The rainfall of thunderstorm is closely related to its numerous cells. There is maximum rainfall in the centre and minimum at the periphery of each convective cell. Fully developed cell yields rainfall for about an hour whereas weak cell dies out within few minutes.

(ii) **Hailstorms** : when condensation occurs below freezing point, ice particles are formed which range from the size of a pea to a large ball. Hail is not associated with every thunderstorm. Not only this, hail is confined to only certain cells of a thunerstorm. Hails fall down on the ground surface when the rising convection currents become weak and feeble. Hails are of three types, namely (i) **soft hail** also known as **graupel**, is less than 5 mm in diameter and is crushed and broken when hits the ground; (ii) **small hail** is mixed with rain and remains intact when it hits the ground surface; and (iii) **destructive hail** also called as severe hail, is very large in size and weighs from few grams to several kilograms in weight. Such destructive hails cause maximum destruction. The sudden fall of hails inflicts great damages to human health and wealth, birds and animals and standing agricultural crops.

(iii) **Lightning** : electrical discharge centers are developed in a mature thudnerstorm. The centres of positive and negative electrical charges develop in the upper and lower portions of the clouds respectively with discharge values ranging between 20 to 30 coulombs. Lightning is produced when the electrical potential gradient between the electrical positive and negative charges becomes very steep. According to another view lightning is produced due to splitting of large water drops. Each water drop has positive and negative electrical charges which remain in neutral state when they are evenly balanced. This balance is disturbed due to splitting of these drops resulting into difference in positive and negative charges.

(iv) **Thundering** sound is produced due to sudden and rapid expansion of air columns caused by intense heat (10,000^{0}C) resulting from lightning strokes. This deafening noise produced by vibrating pressure wave due to rapid expansion of air column as mentioned above is called cloud thunder.

(v) **Squall** : the downward movement and divergence of cold air at the ground surface is called squall. The velocity of squalls is equal to and some times greater than hurricane velocity and hence they inflict greater damage to human structures and vegetation. Squall is produced after the thunderstorm becomes mature and heavy precipitation occurs.

Cloudbursts and Flash Floods

Cloud burst may be defined as sudden localized very heavy downpour with cloud thunder and lightning associated with thunderstorms caused due to forced ascent of moisture laden winds. Though cloud bursts may occur any where whenever ideal conditions are available but they mostly occur in the hilly areas because of orographic barriers and consequent forced uplift of moist air. From this stand point the geomophological set-up of the Himalayas presents most conducive situations for frequent occurrences of cloud bursts because of numerous sites of narrow valleys surrounded by steep valley sides and high reliefs, ablated and active cirques, passes and wind gaps, transverse position of ridges etc. which force the moist winds to ascend quickly and reach condensation level to yield heavy rainfall. The cloud bursts resulting into very high intensity rainfall, say 250-300 mm rains in a couple of hours, if continue for 3-4 days, the ground surface becomes saturated, the Hortonian surface runoff exceeds infiltration and narrow but less deeper valleys become bankfull and ultimately flash floods are caused. The cloud bursts besides causing flash floods lead to accelerated rate of soil erosion, landslides, road damage and blockage, settlement collapse, degradation of forest and agricultural lands etc.

The most vulnerable areas of higher frequencies of cloud bursts in the western Garhwal Himalayas include the tracts of Chamoli, Uttarkashi, Tehri, Rudraprayag and Pauri districts while Pithauragraph, Almora, Bageswar and Nainital of the Kumaun Himalayas are most frequented by cloud bursts and associated problems. Table 19.8 depicts major cloud bursts of the Garhwal Himalayas which caused havoc in the affected areas.

Table 19.8 : Major cloud bursts in Garhwal Himalaya

Location	Month	Year	Altitude (meters)
1. Dhak Nala (Dhauliganga)	July	1970	3700
2. Belakuchi (Birehi river) Chamoli	August	1970	2150
3. Kontha, Chamoli	July	1979	1800
4. Ukhimath	August	1998	2000
5. Neelkanth, Pauri	July	1990	1800
6. Budha Kedar	August	2002	1600-2200
7. Mandakhal, Pauri	August	1981	1950
8. Phata, Bantoli, Rudraprayag	August	2001	1650
9. Mussoorie hills, Dehra Dun	August	2001	1650
10. Medh-Agunda, Tehri	August	2002	1650

Source : B. Sharma, A.K.L. Asthana, and D. Pal, 2003.

19.3 TORNADO DISASTER

1. Meaning and Characteristics

The word **'tornado'** is derived from Spanish word **'tornar'** meaning thereby, to **'turn'** and **'tornada'** which means thunderstorm'. It is known as **twister**' , a special form of a 'cyclone'.

Tornadoes are funnel shaped storms wherein the upper portion is like umbrella in shape while the lower portion is like pipe which touches the ground surface (fig. 19.3). Tornadoes are smallest but violent, awesome, disastrous of all the atmospheric storms and are notorious for destruction of human property and causes human deaths if not forecast well in time to facilitate evacuation. In fact, tornadoes are violently rotating columns of air having upper portion of funnel shape of cumulonimbus clouds which are attached to the ground by very narrow column of air. The tornadoes are characterized by the following salient features :

1. Tornadoes are very violent rotating systems of air wherein the air from the ground surface having lowest pressure is sucked by the upper air and is suddenly uplifted causing convective instability.
2. The pressure in the center of tornado, though not precisely measured as the instruments meant for measuring wind speed and air pressure are destroyed by gusty wind, is extremely low. The recorded lowest pressure (in 1904) of a tornado in the state of Minnesota of the USA was 813 mb. On an average, the center of a tornado is characterized by extremely low pressure, say 100 mb less than the outside environments.
3. The diameter of the upper funnel increases from 90 m in the lower portion say at the base at the ground to 460 m in the upper portion, say at the top.
4. Because of steep pressure gradient winds rush up with great force towards the center having fourious velocity ranging between 400 km to 800 km per hour depending upon the magnitude of pressure gradient. Thus, the swiftly inward rushing air is caught into a vortex of the storm and is rapidly lifted upward and cools adiabatically and forms thunderstorms. This is why tornadoes are always associated with violent thunderstorms.
5. The movement of tornadoes is not in well defined route and direction. Some times, they become stationary at a place. Generally, they move with average speed of 40-60 km per hour, though the speed of movement becomes zero for stationary tornadoes while it in exceptional case may exceed 100 km per hour.

6. Tornadoes follow very narrow paths, the width of which ranges between a few meters to more than 2,000 meters, while the average length of path followed by a tornado is about 40-50 km. The recorded long distance covered by a tornado in the states of Illinois and Indiana (USA) in May 1977 was 570 km.
7. The average duration of existence of a tornado ranges between 15-20 minutes but occasionally they may be in existence for a few hours.
8. Tornadoes look very dark in colour because of the dominance of dusts, sands, debris and condensed moisture.
9. The arrival of tornado is heralded by dark and thick clouds in the sky resulting into complete darkness, minimum visibility and low pressure.
10. Tornadoes move as a single unit or in a group consisting of an average 7-8 in number. The cluster or group of tornadoes is called **tornado family** while occurrence of several tornadoes in succession as a group or cluster is called **tornado outbreak.**

2. Formation of Tornadoes

It may be mentioned at the very outset that exact mode of formation and development of tornadoes (fig. 19.3) is not properly understood by the storm experts and meteorologists because the measurement of wind speed, temperature, humidity, and pressure at the time of their occurrence becomes practically difficult as the instruments are also lifted up and destroyed by the ferocity of the storms but majority of the meteorologists are of the opinion that the primary cause of the origin of tornadoes is violent convection of conditionally or convectively unstable column of warm and moist ascending air. The following are the prerequisite conditions for the formation of tornadoes : (1) mass convergence of air near the ground surface, (2) mass divergence aloft, (3) byoyant air mass, (4) wind shear in the vertical, (5) moist air mass in the lower layers, (6) a trigger mechanism, (7) unstable vertical temperature structure, (8) some preexisting mechanism for rotating the winds, (9) surface cyclogenesis etc.

The origin of tornadoes has also been related to fronts. The upthrusting of warm and moist tropical and subtropical air mass by cold polar air mass along the cold front presents ideal condition for tornado development. Some times, intense local heating of the ground surface causes strong convection which induces ideal conditions for the formation of tornadoes. According to Californian scientist V.J. Rossaw tornadoes develop because of attraction of two cloud masses. Though tornadoes may develop at any time but they are more common during spring and summer seasons.

In the regions of polar frontogenesis tornadoes are formed due to strong collision of warm and moist air mass from tropical and subtropical regions with cold and dry air mass from polar regions. Due to such strong collision strong turbulence develops along the air mass collision boundary, this strong turbulence causes the development of several eddies which develop into powerful wind whirls having rotating winds, these whirls allow the warm, moist and unstable warm air to escape upward like smokes in a factory chimney. The trigger mechanism which causes violent exchange of air of contrasting properties requires some sort of disturbance which may be heat at the ground. The intensely heated ground radiates heat upward which provides energy to the ascending warm air. This causes extremely low pressure at the ground and strong convective mechanism above the ground surface i.e. intense insolational heating of the ground. Extremely low central pressure draws air from all directions. Thus, a rising column of rotating warm air is developed and a tornado storm is formed. Such violent storm is comprised of several super cells. Further violent strong upward movement of warm and moist air results in the formation of enormous thunderstorm having numerous supercells which yield copious rainfall and hails. It may be mentioned that wind shear (change of speed and direction of wind) acts as mechanism to rotate the winds rushing towards the central lowest pressure. As the storm develops into thunderstorm characterized by strong turbulence and updraughts, mamantus ciouds are formed at lowest level of clouds i.e. near the ground surface while funnel clouds develop at the top of thunderstorm. All these are indicators of the formation of a tornado. The funnel clouds drop down and the tornado develops from the cloud wall.

3. Distribution of Tornadoes

Though tornadoes can develop in any part of the world except extreme cold region (fig. 19.4) but the United States of America is most important breeding region of tornadoes. The region to the south of 45^0N latitude and to the east of the Rocky mountains is freequented by tornado outbreak from April to September. The Great Plains present most ideal conditions for the formation of tornadoes where these are associated with frontal activity (cold fronts). The Great Plains are also called **Tornado Alley** because of maximum frequency of their occurrences. The most adversely affected states are Texas. Mississippi, Alabama, Missouri, Oklahoma, Arkansas, Kansas and Iowa. The occurrence of thunderstorms and tornadoes in the USA are synchronous (i.e. they occur at the same time-April to September, during daylight). The occurrence of tornadoes in groups involving large numbers on a specific day are called in the USA **tornado outbreak.** One such tornado outbreak occurred on Feb. 19, 1884 when 60 tornadoes struck the states of Virginia, North Carolina, South Carolina, Georgia, Alabama, Mississippi. Tennessee and Kentucky between 10 A.M. and 12 midnight wherein the most terrible devastation was caused by terrific wind storms ever experienced in the USA before this date. The second important outbreak of tornadoes, known as the Jumbo Outbreak, comprised of 148 tornadoes, struck 12 central states of the USA on April 3 and 4, 1974.

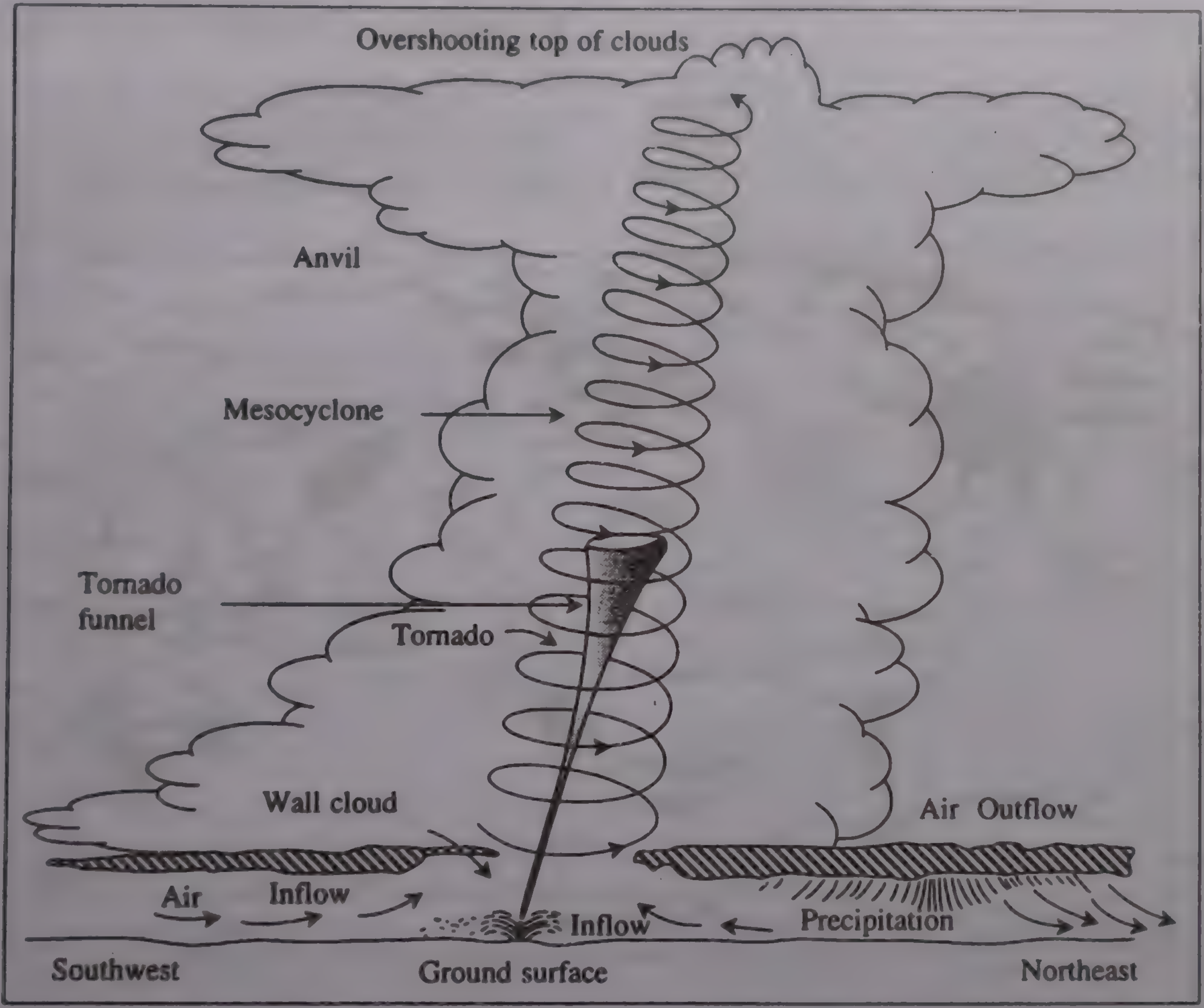


Fig. 19.3 : Development of tornado. Source A.C. Donald, 1988, adapted from Oliver and Hidore, 2003.

Though tornadoes may occur in any month of the year in the USA but highest frequencies of their occurrences are concentrated in three months of

April, May and June (based on data from 1950 to 1997) which account for average number of tornadoes of 104, 171 and 161 per annum (table 19.8). Forty-eight years data (1950-1997) of frequencies of occurrences of tornadoes in the USA denote total occurrences to be 37,760 with mean annual average of 786 tornadoes (table 19.8). Besides the USA, tornadoes also occur in France, United Kingdom, China, Australia, eastern India etc.

Tornado in India

Weak tornadoes, locally called as **'Bawandar'** occur in North India during hot and dry summer months (April, May and June). One severe tornado struck eastern Bihar and West Bengal on April 13, 2010. The salient features were as follows :

- time, 13 April, night
- duration, 30 minutes
- speed, 120-130 km per hour
- people killed, 129
- houses damaged, 200,000
- prediction, no prediction

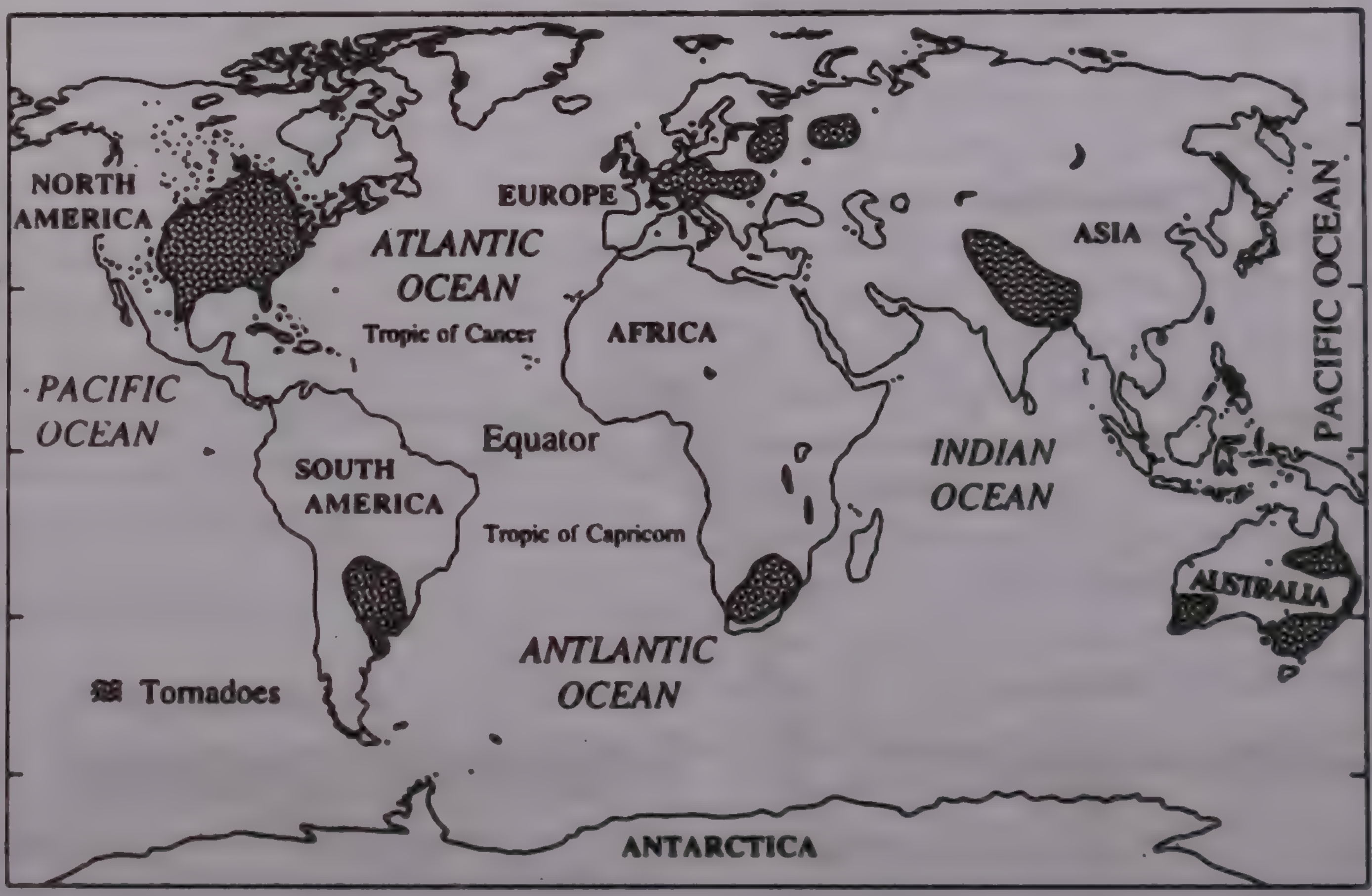


Fig. 19.4 : Tornado areas of the world; source : based on and modified from McKnight, 1996.

4. Severity and Damage Scale of Tornadoes

A scale to assess the relative severity and damage of tornadoes was devised by **T. Theodore Fujita** in the late **1960s** on the basis of wind velocity **and quantum of damage** done by a tornado. This scale is popularly known as **Fujita Scale.** It may be mentioned that the wind speed is not practically measured rather it is estimated after the tornado is over. Based on Fujita Scale tornadoes are divided into three major categories as follows :

1. **Weak tornadoes** are characterized by wind speed ranging between 64 km/hr to 179km/hr. These tornadoes are further divided into two subcategories on the basis of expected damage e.g. **category O : light damage,** branches of trees are broken, sign boards are damaged etc., wind speed from 64 km/hr to 115km/hr; **category 1** : wind speed ranging between 116km/hr and 179km/hr, **moderate damage,** trees are broken, windows of houses broken, broken parts whisked away.
2. **Strong tornadoes** are characterized by wind speed ranging between 180km/hr to 329 km per hour, these are further divided into two subcategories e.g. **category 2** : wind speed between 180 km/hr and 187km/hr, **considerable damage,** large trees are broken and uprooted, moving houses flown, weakly fixed building structures are damaged and removed; **category 3:** wind speed between 188 km/hr and 329km/hr, severe damage, uprooted trees are carried away as tornado missiles, four wheeler and three wheeler

automobiles are overturned and uplifted, roofs and walls of buildings are damaged and removed.

3. **Violent tornadoes** are characterized by very high wind speed ranging between 330km/hr and 509km/hr. These are further subdivided into 2 categories on the basis of wind speed and expected damage e.g. **category 4 :** wind speed ranging from 330km/hr to 416 km/hr, **devastating damage,** houses are destroyed, roofs, trees and automobiles are carried as **tornado missiles; category 5 :** wind speed ranging between 417 km/hr and 509km/hr, **incredible damage.** The above types of tornadoes may be summarized as follows (adapted from Oliver and Hidore, 2003) :

(1) weak tornadoes

Category 0 : wind speed 64 km/hr to 115 km/hr. damage category light

Category 1 : wind speed 116km/hr to 179km/hr, damage category-moderate

(2) strong tornadoes

Category 2 : wind speed, 180 km/hr to 187 km/hr, damage category-considerable

Category 3 : wind speed, 188km/hr-329 km/hr, damage category-severe

(3) violent tornadoes

Category 4 : wind speed 330 km/hr-416km/hr, damage category-devastating

category 5 : wind speed 417km/hr-509km/hr, damage category-incredible.

5. Tornado Hazards

Tornadoes are more common in the southern and eastern USA. The arrival of tornadoes is heralded by dark and thick clouds in the sky resulting into complete darkness and minimum visibility and low air pressure. The wind blows with highter velocity which causes cracks in the buildings. The corcks of bottles suddenly open up automatically due to sudden change (lowering) of air pressure.

Tornadoes, though smallest in area of all the hazardous atmospheric storms, are very deadly to human lives and property. On an average, the annual toll caused by tornadoes in the USA includes damage to property worth 100,000,000 US dollars and 150 human deaths. The deadliest parts of tornadoes are **tornado missiles** (consisting of uprooted trees, their branches, roofs of buildings etc. which are carried away by the dynamic force of winds) which inflict great damage to buildings, other human structures, and human lives. A tornado, for example, at Lubbock (Texas, USA) in 1970 moved a long cylindrical fertilizer tank (3.35m X 12.5 m in size with average weight of 11 tons for a distance of 1.21 km from its original place. It may be pointed out that a tornado becomes disaster only when its funnel of dark clouds moves by touching the ground through narrow column of swiftly moving wind. The **tornado outbreak** (occurrence of tornadoes in groups involving large numbers) of 60 tornadoes on February, 19, 1884 struck the states of Virginia, North Carolina, South Carolina, Georgia, Alabama, Mississippi, Tennessee, and Kentucky between 10 A.M. and 12 midnight wherein the most terrific devastation was caused by violent wind storms ever experienced in the USA before this date. Total damages caused by these tornadoes included loss of property worth 3 to 4 million US dollars, death of 800 persons, injuries to 2,500 people, destruction of 10,000 buildings, homeless and destitute people numbering 10,000 to 15,000.

The following reporting in the news paper, the Washington Post, presents a vivid picture of the sad story of 1884 outbreak of tornadoes :

> *"The centre of the storm struck the outskirts of Rockingham with such fury that people were unable to escape from their houses. Buildings were blown into fragments. Some bodies were found under the timbers, other were carried by the wind 150 to 300 yards. A woman was found clasping to her breast an infant scarcely a month old; both were dead. The bodies of victims were terribly bruised and cut, presenting a ghastly appearance. The force of the wind was such that two millstones were moved 100 feet. Chickens and birds were picked clean, except the feathers on their heads." (Willimington (N.C.) Star in The Washington Post, 22 February, 1884).*

The second important outbreak of tornadoes, known as the Jumbo Outbreak comprised of 148 tornadoes, struck 12 central states of the U.S.A. on April 3 and 4, 1974. The city of Xenia in Ohio state was worst affected by the tornado which destroyed 5 schools within the city. Like 1884 outbreak of tornadoes this outbreak also largely affected rural areas and avoided large cities. Total damage caused by these tornadoes in 12 US states included deaths of 300 people and injuries to 5,000 persons.

Table 19.8 : Frequency of tornadoes and human causalties in the USA between 1950-1997

Months	Total number of tornadoes	Mean number of tornadoes	Total number of human deaths	Mean number of human deaths
January	716	15	106	2
February	975	20	274	6
March	2514	52	602	13
April	5002	104	1245	26
May	8185	171	883	18
June	7715	161	521	11
July	4509	94	63	1
August	2806	58	112	2
September	1829	38	75	2
October	1298	27	82	2
November	1398	29	149	3
December	810	17	124	3
Total	37,760	—	—	—

Source : J.E. Oliver and J.J. Hidore, 2003.

6. Prediction of Tornadoes

The prediction of formation of tornadoes is very difficult because of its localized nature and very small size but violent nature, random distribution over space etc. The moment tornadoes are located after their formation their movements are tracked by radar system and the warning of their destination becomes possible but the time available is so short that destruction becomes inevitable destiny.

'The unpredictability and ferocity of tornadoes make protection and preparedness very difficult. Nevertheless, in the period that tornado forecast and warning services have been in operation in the U.S.A. the annual average number of fatalities seem to have decreased markedly ' (J.E. Hobbs, 1980). According to G.P. Gressman (1969) the average number of annual deaths due to tornadoes is decreasing every year as average number of deaths between 1916 and 1952 was 200 per year but this figure was reduced to 120 between 1953-1968 because of improved warning systems. The forty-eight-year data of human casualties denote average annual death of only 70 people. Two methods of **operational detection and tracking of tornadoes** are in practice in the U.S.A. viz. (i) detection and tracking of tornadoes by **weather surveillance radar,** and (ii) prompt reports of visual sightings by competent observers.

The following agencies handle different aspects of tornado forecast in the USA :

1. The National Severe Storm Forecast Center (NSSFC), established in the year 1952, sends the signals of probable potential severe weather conditions including the formation of tornadoes to the weather forecast centers.
2. The National Severe Storm Laboratory (NSSL) handles the tracking aspects of moving tornadoes and sends information to concerned centers, such as NWS.
3. The National Weather Service (NWS) issues warning messages of the movement, tracks and severity of tornadoes.

Recently, **doppler radars** are used in the study of different aspects of tornadoes and their prediction and warning. It may be mentioned that a mesocyclone takes 20 minutes time to develop into tornado and hence doppler radar predicts the arrival of a tornado at a particular locality 20 minutes in advance. The doppler radar also determines the speed and direction of tornado and hence it has now become possible to forecast the likely track of a tornado.

It is apparent that the only effective measure to mitigate tornado disaster is to issue quick warning messages which may reach general public before 20-minute time so that people may move to safer places. Thus, the public should always be in a state of preparedness during tornado period, mainly during April, May and June because tornadoes in the USA follow a seasonal pattern, i.e., they are more frequent during summer season.

19.4 CUMULATIVE ATMOSPHERIC HAZARDS

Cumulative atmospheric hazards are those events which are caused due to cumulative effects of weather events which prolong for longer period of time ranging from a few weeks to several years depending upon the nature of the weather events. For example, any hot day may not become disastrous or hazardous but when very hot and dry days prevail for a few weeks in continuation, environmental hazards in the form of heat waves occur which affect the environment and human lives, plants and animals. The persistence of exceptionally cold conditions for several days causes severe snowfall. A dry season in a year may not be as much disastrous as continued dry seasons for several years. The perception and concept of drought vary from place to place and from one group of people to other group based on profession and occupation. In fact, drought occurs when there is appreciable decrease in rainfall from the average normal rainfall. Floods are still very severe environmental hazards which are related to atmospheric processes. Mississippi flood plains (U.S.A.) and the Ganga plains (India) are frequented by severe flood hazards. It may be pointed out that floods are not always hazards rather these are also boon because these bring rich fertile alluvial soils each time and thus increase agricultural productivity. The significant atmospheric cumulative hazards include floods, droughts, heat waves and cold waves.

19.5 FLOOD HAZARD AND DISASTER

1. Meaning and Concepts

Flood simply means inundation of extensive land area with water for several days in continuation. Generally, floods are considered to be associated with rivers and people conceive floods as the outcome of accumulation of huge volume of water coming out of the rivers through overtopping of river banks during peak discharge period. In fact, flood is an attribute of physical environment and thus is a component of hydrological cycle of a drainage basin. It may be pointed out that flood is natural phenomenon and is a response to rainfall but it becomes hazard and disaster when it causes colossal loss to human lives and property. It is also important to note that floods are also aggravated by human activities and thus flood hazard is both natural as well as man-induced rather man-accentuated phenomenon. Floods are very often associated with alluvial rivers draining extensive alluvial and flood plains. About 3.5 per cent of the total geographical area of the world is covered by flood plains which house about 16.5 per cent of the total population of the world. The most notorious rivers of the world in terms of devastating floods and resultant damage to natural environment (riparian decay) and loss of human lives and property are the Ganga and its major tributaries such as the Yamuna, the Ramaganga, the Gomti, the Ghaghra, the Gandak, the Kosi, the Damodar etc. (northern India), the Brahmaputra (north-east India), the deltaic segments of the Mahandi, the Krishna, the Godavari, the Tapi, the Narmada, the Luni, the Mahi etc. (all in India), the Mississippi and Missouri (U.S.A.), the Yangtze, the Yellow (China), the Irrawadi (Myanmar), the Indus (Pakistan), the Niger (Nigeria), the Po (Italy), the Euphratus and Tigris (Iraq) etc.

Besides river floods which involve extensive areas, there are localized floods such as urban floods, coastal floods, etc. The urban or city floods are in fact the result of water logging caused by extremely heavy rains (more than 250 mm within 24 hours). Such water logged floods occurred in Mumbai in the last weak of July, 2005 when more than 944.2 mm of rainfall was recorded within 24 hours on July 26. Similar situation developed in Mumbai in the 1st week of July, 2006 when heavy rains occurred in couple of days (since July 2 to 6, 2006). Coastal floods occur due to strong storm surges when a few meters high tidal waves transgress into low coastal zones but such situation does not persist for longer duration but great damage is done to human health and wealth.

Thus, floods are divided into the following three broad categories :

types of floods
- land-born floods or river floods
- coastal floods or storm surge flooding
- local water logged-flooding

2. Causes of Floods

Since the floods of rivers are the responses of both natural and anthropogenic factors, the causes of floods of the alluvial rivers become highly complex and their relative importance varies from place to place. Among the natural factors which cause river floods, important are prolonged high intensity rainfall; meandering courses of the rivers; extensive flood plains; break in slope in the long profiles of the rivers i.e. sudden change in channel gradient at the intervening zones of foothill slope of the mountains and upper end of the plains; blocking of free flow of the rivers because of enormous debris provided by landslides and due to volcanic eruptions; nature of river valleys and channels etc. Anthropogenic activities such as building activity and eventual urbanization, channel manipulation through diversion of its (of the river) course, construction of bridges, barrages and reservoirs, agricultural practices, deforestation, land use changes etc. by man invite several hazards in the river system viz. disastrous floods, landslides and slumping along the banks, massive erosion along the river banks causing large-scale riparian decay, shifting of channels and even of the river courses, silting of beds, deposition of sands, silts and clays in the flood plains etc. which pose a serious threat to human society and necessitate river regulation and flood control (Savindra Singh, 1983). The following causes may be held responsible for devastating floods of alluvial rivers. It may be pointed out that these factors should never be considered separately because it is the cumulative effects of several factors which ultimately cause severe floods.

- heavy incessant rainfall,
- spell of extremely heavy rainfall,
- highly sinous and meandering courses of rivers,
- large-scale deforestation,
- increased urbanization,
- faulty agricultural practices,
- blocking of natural flow of water etc.

Heavy Rainfall

Heavy rainfall for long period in continuation is the root cause of river floods because immense volume of water either through high-intensity rainfall or large-scale snow-melt is the prerequisite condition for river floods. Heavy rainfall in the upper catchment areas of the concerned river causes sudden increase in the volume of water downstream. This causes overtopping of river banks by enormous volume of water and consequent inundation and flooding of flood plain areas. It may be pointed out that the occasional heavy rainfall resulting from strong rainstorms can cause severe floods only in those regions which are characterized by seasonal regime of rainfall or say seasonality of rainfall such as the regions of monsoon climate (rainfall during 4 wet summer months e.g. June to September), Savanna climate (rainfall during wet summer months), Mediterranean climate (rainfall during wet winter months) etc. because of the fact that the rivers maintain very low flow and low discharge of water during most part of the year and hence sudden torrential rainfall causes sudden increase in the volume of water which cannot be disposed off by the rivers immediately and thus the river banks are overtopped by the swelling water and instantaneous floods are caused.

The unprecedented flood of the Lower Damodar river in West Bengal due to torrential cyclonic rainfall of September 26-29, 1978 explains the impact of high intensity rainfall as a potent causative factor of floods. The severe cyclonic storm yielded heavy rainfall totalling 600 mm between September 26-29, 1978 in the upper catchment of the Damodar river (falling in Jharkhand, India) and 500 mm in its lower catchment (falling in West Bengal) thus giving an average amount of 550 mm within a 3-day period (September 27-29, 1978). It may be pointed out that the Damodar river is a controlled river through a series of dams and reservoirs on the main river and its tributaries such as Panchet dam, Maithan dam, Konar dam, Tilaiya dam etc. under the scheme of Damodar Valley Corporation (D.V.C.).

The combined outflow of water from Maithan and Panchet dams, was 16,000 cusecs (cubic feet per second) on September 23, 1978 and 10,000 cusecs on September 26 (upto the 6th hour), 1978 just before the outbreak of torrential rainfall from strong cyclonic storm centered in the upper catchment of the Damodar river. The torrential incessant rainfall resulted into enormous surface runoff which immediately reached the master stream and thereafter the reservoirs constructed behind the dams on the Damodar and its tributaries. Rapid pouring of enormous volume of water into the reservoirs caused quick rise in the level of reservoirs water and hence the discharge of outflow from the dams downstream had to be increased. Thus the outflow of water increased from 10,000 cusecs to 100,000 cusecs in the 24th hour of September 26 in response to the beginning of torrential rainfall in the upper catchment area. The discharge of outflow was noted on the next consecutive days as 160,000 cusecs on the 24th hours of September 27, 1978, 161,900 cusecs on the 3rd hour of September 28, 100,000 cusecs on September 29 and 60,000 cusecs on September 30, 1978.

Heavy rainfall also in the lower catchment having alluvial plains of West Bengal amounting to 500 mm within 3-day period and high discharge of water coming from upstream segment of the Damodar further augmented the discharge which was recorded as 379,800 cusces on the 12th hour of September 27, 1978. This high discharge of water could not be accommodated in the valley of the Damodar in its lower reaches and hence devastating flood was generated which destroyed agricultural crops, caused heavy loss of human lives and property. High intensity rainfall giving average annual amount of 2500 mm in the plain area and 5000 mm in the hilly sector in Assam (India) causes frequent floods of high magnitude through the Brahmaputra river almost every year. High rainfall in the Himalayas and in the plains causes disastrous floods in the Himalayan rivers draining through the North India Plains or the Ganga plains.

Heavy Spell of Rainfall

Heavy spell of rainfall in arid and semi-arid areas where the rainfall is scant, low and infrequent causes flash floods because such areas have poor natural drainage systems and existing rivers and streams are unable to accommodate enormous volume of water caused due to huge volume of runoff resulting from high intensity rainfall during occasional rainstorms. For example, unprecedented rainfall of 836.4 mm between July 17, 1981 and July 21, 1981 in and around Jaipur city (Rajasthan, India : July 17-4.2 mm.; July 18-235.8 mm;, July 19-353.6 mm., July 20-228 mm, July 21-14.2 mm) caused flash floods because the chocking and blocking of lateral drainage from the hill through the dunes by human activity has resulted in a situation whereby this catastrophic runoff could not be eased out (H.S. Sharma, 1983).

A spell of 24 hours of very heavy rainfall yielding a record rainfall of 944.2mm in past 95 years (upto 2005) from 8.30 a.m. on July 26, 2005 to 8.30 p.m. on July 27, 2005 created hovoc of disastrous flood in Mumbai. Almost similar situation developed in Mumbai in the first weak of July, 2006 resulting into flooding of the city due to incessant rainfall. Many parts of the city reeled under waist-deep water for 5 days (July 2 to 6, 2006). Earlier Mumbai faced disastrous water-logged flooding on July 5, 1974 when Colaba and Santacruz received 575.0 and 375.2 mm of fainfall respectively.

Torrential rainfall on August 6, 7 and 8,2006 resulted in devastating floods in many parts of Gujarat where Surat city was the worst affected as the 200-year record of flood of the city was shattered. More than 250,000 people were adversely affected. Many parts of Maharashtra, Gujarat, Madhya Pradesh and Chattishgarh were marooned by dangerous floods caused due to very heavy rainfall for 4 days in continuation during August, 2006.

Sinuous and Meandering Courses of the Rivers

Highly sinuous and meandering courses of the rivers obstruct the normal discharge of water and thus the velocity is reduced which delays the passage of water resulting into stagnation of water. Consequently, the meandering valleys are immediately overflown and meander belts and loops are flooded.

Deforestation

Large-scale deforestation in the upper catchments is perhaps the most important anthropogenic factor of the causes of the river floods. Large-scale deforestation effected by man for various purposes (such as for extension of agricultural land, for the supply of raw materials to the factories, for domestic uses as firewood, for commercial purposes etc.) decreases infiltration capacity of the cutover land and consequently increases surface runoff which helps tremendously in increasing the magnitude of floods. It may be pointed out that dense vegetation allows maximum infiltration of rainwater into the ground because rain drops are intercepted by forest canopy and thus reach the ground slowly in the form of **aerial streamlets** through the leaves, branches and stems of trees and hence infiltrates easily into the spongy soil layer, formed because of decomposition of fallen leaves (leaf litters). On the other hand, in the absence of forests and other vegetation covers raindrops stike the ground surface directly and in case of heavy downpour the rainfall exceeds the limit of infiltration soon and thus maximum runoff is generated which reaches the rivers through rills, rivulets and streams and causes floods.

Increased surface runoff also accelerates the rate of soil erosion and thus increases the sediment load of the rivers. Increased sediment load causes siltation of river beds and filling of the valleys. This process results into gradual rise in the river beds and decrease in the cross sectional areas of the valleys and hence reduction in the water accommodating capacity of the river valleys. All these chain effects of deforestation and related increased surface runoff, increased soil erosion and decreased cross sectional areas of the valley not only cause floods but also increase the magnitude and dimension of floods. Large-scale deforestation in the Himalayas for the last one hundred years or so has resulted into phenomenal increase in the frequency, magnitude and dimension of floods in those rivers which have their source catchments in the Himalayas but extensive drainage areas in the alluvial Ganga plains such as the Ganga and its tributaries like the Yamuna, the Ramaganga, the Gomti, the Ghaghra, the Gandak, the Buri Gandak, the Kosi etc. The extent of damages caused by swollen alluvial rivers and recurrent floods in the states of Uttar Pradesh, Bihar and West Bengal (India) is increasing every year.

Increasing Urbanization

Increasing urbanization also helps in increasing the surface runoff and therefore dimension and magnitude of floods because extension in the pucca ground cover through the construction of buildings, courtyards, roads, streets, pavements etc. reduces infiltration of rainwater significantly and increases surface runoff considerably which increases the volume and discharge of storm drains of urban areas. Thus, the rainwater resulting from torrential rainfall is quickly disposed off through the city storm drains to nearby streams and thus the volume of river water is increased causing floods. Besides, obstruction of river flow due to bridges across the rivers, silting of river beds due to pouring of wastes and garbages from the nearby urban centres, gradual encroachment of human settlements towards the channels and lowlying areas, filling of 'nallas' (natural urban drains), construction of new roads and bridges etc. are also significant factors (related to urbanization) of floods which not only degrade the physical environment of the rivers and surrounding terrains but the recession of deluge also causes accumulation of human refuse, sewage materials, silts etc. bringing the epidemics and thus degrading the human environment in most of the riverine cities of alluvial regions of the developing countries in general and India in particular (Kanpur, Allahabad, Varanasi etc. located along the mighty Ganga river are burning examples of degradation of environment caused by recurrent floods of the Ganga river at frequent intervals).

Uncchecked urban growth has been responsible for water logging and consequent urban flood in Mumbai in the last week of July 2005 and 1st weak of July 2006. Though major cause of Mumbai flood was very heavy rainfall of more than 944 mm on July 26 and 27, 2005 but the rainwater could not find easy exit due to chocking of storm drains.

Faulty Agricultural Practices

In India **valley side slopes of alluvial rivers** are ploughed down to the channel transverse to the channel or say transverse to the contours (inorder to dry out the moisture accumulated due to alluviation during floods) during 'rabi season' (winter cropping season) and the farms are never irrigated. After the crops are harvested, the ploughed fields are baked hot in the scorching sunlight of summer months with the result loose soils become extremely dry. These dried soils are soaked with water during first summer showers and are slumped into the river bed by overland flow. This slumping of moistened soils results in the gradual silting of river bed. On the other hand, the cultivation of valley-side slopes reduces the gradient of river banks. These two processes flatten the valley and thus reduces the water accommodating capacity of the river valley with the result the river takes very little time in attaining its bankfull capacity and afterward water spreads over the valley sides, inundates the low lying flood plains and helps in aggravating the flood situation.

Blocking of Natural Flow of Rivers

Blocking of natural flow of the rivers by landslides caused by earthquakes, other natural factors and anthropogenic factors and clearance of such blockades causes sudden severe flash floods in the downstream sections of the rivers. Similarly, breaches in the dams constructed across the river also cause devastating floods in the downstream segments.

3. Floods Disaster in India

Most of the flood-prone and flood affected areas of the country are located in the northern parts mainly in the Ganga plains of the states of Uttar Pradesh, Bihar and West Bengal. The flood hazards and disasters in Uttar Pradesh, Bihar and Andhra Pradesh combined together account for 62 percent of the total damages caused by flood hazards in the country. Table 19.9 presents the statewise damages caused by flood hazards in India.

Table 19.9 : State-wise share of damages done by floods (in percentage) (average of 1971-78)

States	Share of damages (in percentage)	States	Share of damages (in percentage)
Bihar	23.9	Rajasthan	4.5
Uttar Pradesh	23.8	Tamil Nadu	3.8
Andhra Pradesh	15.4	Haryana	3.2
West Bengal	7.0	Assam	2.1
Gujarat	5.7	Punjab	1.4
Orissa	4.5	Madhya Pradesh	1.3

Source :National Commission on Floods, 1980, Ministry of Energy and Irrigation, New Delhi.

It may be pointed out that there is constant increase in the frequency, intensity, spatial coverages (dimensions) and magnitude of damages of floods in India every year because of a bunch of causative factors such as rapid rate of deforestation in the source catchments of major rivers and their tributaries and consequent accelerated rate of soil erosion, increase in sediment load of rivers, siltation and rise of river beds and marked reduction in the water accommodating capacity of the river valleys; increasing urbanization, mushroom growth of settlements in the floodplains and even in the flattened (due to alluviation) valleys; encroachment of agricultural practices upon the valley sides and even down to the channels; construction of bridges, embankments and dikes etc.

'During recent years, both the frequency and intensity of floods have increased significantly. For example, compared to 1950-65, the average loss from floods got doubled in 1966-67 and went upto 3 times in 1971-75 and 5 times in 1976-78 showing a constant upward trend. According to another estimate, the loss caused by floods within two years (1976-78) remained more than 5 times as compared to earlier period of twelve years...As National Commission on Floods reports, the country suffers a damage of Rs. 1000 crores every year on this account and the figure is rising steadily. What is more, the total area subject to flooding has doubled from 20 million ha (hactare) in 1971 to 40 million ha in 1981' (J. Singh and D.N. Singh, 1988). Table 19.10 depicts the damages done by flood hazards in India during 20-year period (1953-75).

Table 19.10 : Magnitude of flood damage in India

Details of Damages	Average during 1953-1975	Annual Maximum Damages
Areas affected by floods	7.4 million hactares	1.372 million hactares
Cropped areas affected	3.1 million ha	7.6 million ha
Number of houses damaged	8,00,000	23,10,000
Number of cattle lost	50,331	270,000
Number of persons died	742	3,498
Total direct losses	Rs. 2104 million	Rs. 8,850 million

Source : National Commission on Floods, Vol. I, Ministry of Energy and Irrigation, Govt. of India, 1980.

4. Management of Flood Disaster

The following steps should be taken for the reduction and management of flood hazards and disaster :

- Preparadness (P),
- Mitigation (M),
- Prevention (P),
- Rescue operation (R),
- Relief work (R),
- Recovery (R), and
- Rehabilitation.

Let us discuss the preventive steps first. The following flood control measures should be adopted to mitigate the adverse impacts of severe floods and to prevent ordinary floods :

- delay the return of runoff resulting from torrential rainfall to the rivers,
- hasten the discharge of river water,
- divert the flow of rivers, and
- reduce the impacts of floods.

It may be pointed out that the floods are natural phenomena and one cannot entirely get rid off them but their impact can be minimised by man's technological skill, better warning systems and positive human response to flood warnings and various control measures adopted by the governments.

(1) Delay the Runoff

The first and foremost step to control floods is to look into their basic cause which is perhaps the high intensity rainfall and resultant surface runoff. Man cannot stop high intensity rainfall and there is no need at all to interfere with natural processes. What man can do is to delay the return of surface runoff resulting from the high intensity rainfall to the rivers. This can be achieved by large-scale reforestation and afforestation in the hilly source catchment areas of those rivers which are notorious for their recurrent disastrous floods. The thick vegetal covers mostly of dense forests help in this regard in a number of ways as follows :

- Forests delay the return of rainwater to the rivers because these intercept the falling raindrops and leaf litters and herbaceous ground covers hold waters.
- These encourage more infiltration of rainwater and therefore reduce, though marginally, amount of surface runoff.
- These significantly reduce soil erosion and hence reduce sediment load of the rivers,
- Marked reduction in soil erosion and sediment load discourage siltation and hence reduction in the water accommodating capacity of the rivers etc. It is therefore apparent that making the hills, having the source of flood producing rivers, green through large-scale tree plantation can effectively reduce the frequency and dimension of floods.

(2) Hasten the Discharge of River Water

It has ahready been mentioned that too much bends and meander loops in the highly sinuous and meandering rivers retard the quick disposal of water. It is, therefore, advisable to straighten the sinous and meandering courses of the rivers at some places (where meanders and loops have become extremely sharpened) by performing artificial cutoffs of individual bends or a series of bends so that the flood discharge may move downstream more rapidly and the water may be disposed off by the rivers quickly. Such devices are required to train the alluvial rivers because these rivers (like all of the alluvial rivers of the Ganga plains e.g. the Ganga, the Ramaganga, the Rapti, the Gomti, the Gandak, the Kosi etc.) develop highly meandering courses due to alluvial filled flat terrain. There are two main difficulties in the implementation of these control measures e.g. (i) the device requires huge money which may not be easily forthcoming in the developing countries, and (ii) meandering is a natural process of alluvial rivers, if meanders are removed at some places the river may develop meanders at other places. The lower Mississippi river near Greenville (U.S.A.) was shortened in its length from 530 km to 185 km between 1933 and 1936 to reduce flood crests. Similarly, the Missouri river (U.S.A.) was shortened in its length by 52 km between Sioux City and its confluence with the Mississippi in 1960 for flood control and navigation improvement.

(3) Reduce the Volume of Water

The volume of water during flood stage of a river may be reduced through a series of engineering devices such as construction of flood-control storage reservoirs. Such storage reservoirs impound enormous volume of water during flood period and thus these help in two ways e.g. firstly, these storage reservoirs reduce the volume of water of the rivers, and secondly, these provide water for irrigation and drinking purposes. If the reservoirs are succeeded by huge dams, they also help in the generation of hydroelectricity.

Such flood-control reservoirs were constructed on Miami river in the state of Ohio (U.S.A.) as early as in 1913. A series of storage reservoirs were completed by 1921 and thus the scheme of the construction of storage reservoirs as effective flood-control measure became very popular in the U.S.A. The Tennessee basin of the U.S.A. was considered to be hell till 1933 because of perpetual waterlogging, recurrent floods, very high incidence of malaria, typhoid and tuberculosis, accelerated rate of soil erosion and increase in the infertility of the soils and wasteland. But the construction of a series of dams and reservoirs under the scheme of Tennessee Valley Authority (T.V.A.) since 1933 has not only controlled the recurrent floods and tamed the mad Tennessee river but has entirely changed the social and economic picture of the basin to such an extent that the basin once considered as 'hell and curse' is now considered as heaven.

The success of TVA attracted more countries to launch multi-purpose river projects for watershed management. The scheme was also implemented in India to check floods and for other purposes. The Damodar Valley Corporation (DVC), a multi-purpose river project, was launched on the line of TVA wherein 4 major dams and reservoirs have been constructed on the Damodar river and its tributaries such as the Barakar and the Konar rivers for water storage and flood moderation in the lower reaches of the Damodar river. Besides flood control, the DVC also generates hydroelectricity and provides water for irrigational purposes. 'The four dams namely Konar, Maithan, Panchet Hill and Tilaiya have a flood storage of 1603 million cubic metres and have been in operation since 1958 and have helped considerably in the moderation of floods in the Lower Damodar Region' (K.L. Rao, 1975). Similarly, the construction of Ukai Dam and Reservoir on the Tapi (Tapti) river has almost saved the lower reaches of the river and the town of Surat from the disaster of flood hazards. Many more examples may be cited to demonstrate the positive effects of storage reservoirs on flood control.

(4) Divert the Flood Water

Flood-diversion systems imply diversion of flood water in lowlying areas, depressions or artificially constructed channels bordered by artificial dykes so that the flood crests may be reduced and the flood magnitude may be decreased. For example, Ghaggar Diversion Schemes divert the water discharge of about 340 cumecs (cubic metres per second) before entering Rajasthan (India) into the depressions and in the areas between the sand dunes during flood period so that discharge of water in the main river (the Ghaggar) during flood stage may be kept within the safe limits.

(5) Reduce the Impacts of Floods

Embankments, dikes and flood walls are used to confine the flood water within the valley or say within a narrow channel. These engineering works include the building of artificial levees of earthen materials, stones or even concrete walls. Artificial bunds (levees) of mostly earthen materials have been constructed to protect many of the riverine cities and towns in the Ganga plains (such as Delhi, Allahabad, Lucknow etc.). Construction of dikes or artificial levees was practiced long ago in China, India etc. but there were several cases of breaches of earthen dikes and consequent more disastrous floods than natural floods. 'For example dike failures in great flood on the Hwang Ho River (now Yellow river) in China in 1887 brought inundation to an area of 50,000 sq miles (130,000 sq km) and death by drowning to approximately one million persons' (A.N. Strahler and A.H.Strahler, 1976). Besides, protection to the towns and cities from floods by constructing dikes and other engineering structures such as revetments, artificial levees of earthen dikes are also constructed on either side of the river for longer distances to protect the floodplains from floods. For example, the Kosi flood embankments running for 246 km are being used to check the westward shifting of the Kosi river (in Bihar, India) and to protect the fertile floodplains from recurrent floods and deposition of sands and coarse silts which used to render vast tracts of fertile lands unfit for cultivation. It may be pointed out that the Kosi river before the construction of flood embankments has shifted its course westwards by about 112 km. The 246 km long embankments on either side of the Kosi river have been kept wide apart about 12 to 16 km so that broad areas confined between the artificial walls (embankments /dikes) may serve as silt trap.

The Bagmati Flood Control Embankments running for a distance of 241 km and 290-km long embankments along the Mahnanda river under Mahananda Embankment Scheme protect about 57,000 hectares and 160,000 hectares of floodplains respectively.

Stone spurs are also used to protect the towns, cities and other important places from severe erosion during and after the floods. Under the scheme of Dibrugarh Town Protection Works stone spurs, semi-permeable spurs, pile spurs, revetments and protective dikes of about 10 km length have been constructed to protect the town from floods and erosion by the Brahmaputra river. The Jalpaiguri Town Protection Works (India) include the construction of 16-km long embankments and the shifting of existing outfall of the Karala river into the Teesta river near Jalpaiguri by 6 km downstream.

Flood Forecasts and Early Warning

Flood Control Organisation and Flood Forecasting and Warning System in India : The Constitution of Central Flood Control Board in 1954 and the establishment of the State Flood Control Boards at state level have proved beneficial in adopting several flood control measures. The flood forecasting and warning system was started in India in 1959 to monitor the flood situation in the capital city of Delhi. Since then a network of flood forecasting and warning systems has been spread over the country to monitor the flood conditions of major river basins of the country. Thus the flood forecasting centres set up in various parts of India help in the forecasting of floods in the Ganga and its tributaries (e.g. Rapti, Gomti, Ghaghra, Yamuna, Burhi Gandak, Kosi, etc.), the Brahamaputra and its tributaries (i.e. Pagladiya and Burhi Dehing, Bark, Teesta), Subarnarekha, Damodar, Brahmani, Baitarni, Tapi, Narmada, Sahibi, Godavari, Ajoy, Betwa and other flood-prone rivers. The flood forecasting centres collect data of rainfall and discharge rate, gauge level or flood level from various data recording centres in the jurisdiction of each flood forecasting centre and thus warn the inhabitants of particular river basin about the possible danger of floods much in advance, so that people may be evacuated to safer places.

There is immediate need for **Flood Information System** (FIS) which may communicate the concerned governments for issuing timely warning messages to the inhabitants of the area likely to be affected by flood hazard. Information technology and communications have proved very useful for flood forecasting and warning systems.

It may be mentioned that flood forecasting and warning system is well organized in India and flood warning messages are communicated in time through electronic and print media. The concerned authorities also alert the people about immediate flood occurrence but the social constraints taboo the evacuation plan because people are always scared of theft of their property in case they evacuate their homes and move to other places.

19.6 DROUGHT HAZARD AND DISASTER

Meaning and Causes of Drought

Droughts are more deadly natural environmental hazards because these are direcly related to one of the three basic requirements of any form of life (such as water, air and food) that is water and are indirectly related to food because crops and other plants and animals exclusively depend upon water. Droughts resulting from accumulative effects of water scarcity cause extensive and enormous damage to agriculture and natural vegetation and therefore cause famine and starvation of human and animal population of the region concerned. The meaning and definition of droughts are difficult propositons because there are much variations in the viewpoints and perception of droughts from one region to another and from one group of people to another. 'Most people are reasonably well aware when a drought situation exists, but it is very difficult to find an overall acceptable definiotn of drought. It clearly involves a shortage of water but can really be defined only in terms of a particualr need. The most common view of drought is of rainfall deficiency, but the links between rainfall and the water which becomes available to meet a demand are complex. Therefore, definition of a drought relates not only to water needs but also to the complex set of factors involved to supply that need through the hydrological cycle' (J.E. Hobbs, 1980).

It may be pointed out that increased dryness for prolonged period causing drought conditions is related to the amount of rainfall, its departures from normal average annual value and local demand of water for various purposes. It is not the amount of total annual rainfall which matters for drought or wet conditions rather it is the regularity and irregularity of rainfall which matters more. For example, a more persistent and reliable amount of 200 mm of annual rainfall may not be the cause of concern of the agriculturists in dry region because their agricultural activities woud be adapted to this meaagre amount of rainfall but the receipt of only 200 mm of annual rainfall for a few years in continuation or even in a single year in those areas which receive normal annual rainfall of 500 to 800 mm may cause crop failure and hence disastrous drought condition may prevail. According to C.E. Hounam et al. (1975) 'The agriculturist or pastoralist, especially in the direr regions, has assessed the nature of local rainfall and, through years of long and sometimes bitter experience, has learned to adapt his operations to the rainfall characteristics of the area.' 'In other words, drought is related to the failure of the usual rains at a particular time, since most activities using water will be geared to that much is normally available' (J.E. Hobbs, 1980).

It is, thus, obvious that rainfall is the main parameter for the determination of droughts but 'rainfall values, however, have limitations as drought indicators, so many definitions and indices incorporate other parameters such as evaporation, humidity, air temperature, solar radiation, wind, soil moisture, streamflow and plant conditons' (J.E. Hobbs, 1980). The following are a few drought definitions based on the parameters of precipitation :

(i) **C.G. Bates (1935) :** Annual precipitation is 75 per cent or less of normal precipitation and monthly precipitation is 60 per cent or less of normal monthly precipitation.

(ii) **BRO (British Rainfall Organization, 1936) : absolute drought :** when there are atleast 15 consecutive days with less than 0.01 inch of rainfall per day. **partial drought :** when there are at least 29 days having mean rainfall of 0.01 inch or less. **dry spell :** when 15 consecutive days receive less than 0.04 inch of rainfall per day.

(iii) **J.C. Hoyt (1936) :** Annual and monthly rainfall less than 85 per cent of normal rainfall.

(iv) **V.A. Conard (1944) :** Period of 20 or more consecutive days without 0.25 inch precipitation in 24 hours (during March-September).

(v) **D.A. Ramdas (1950) :** When rainfall for a week is half normal or less.

(vi) **A.J. Henry (1960) :** 21 days or more when rainfall is 30 per cent or less of average rainfall. Extreme droughts occur when rainfall is less than 10 per cent of average rainfall for 21 days or more.

Most of the aforesaid definitions of droughts do not have any relevance in India and in many of the tropical and sub-tropical countries because here agricultural practices are associated with distinct seasonal water regime. Failure of monsoonal rainfall in India and addjacent countries adversely affects 'kharif crops' and causes drought conditons. According to Indian Meteorological Department (IMD) drought is defined as a situation occurring in any area when the mean annual rainfall is less than

75 per cent of the normal rainfall. IMD has further classified droughts into two broad categories viz. (i) **severe drought** when the deficiency of rainfall exceeds 50 per cent of the normal rainfall, and (ii) **moderate drought** when the deficiency of rainfall is between 25 per cent and 50 per cent of normal rainfall.

Palmer Index is generally used to determine wet or dry conditions as given below :

Palmer Index of Drought Severity

Above	—	+4.0	extreme moist condition
+3.0	—	+3.9	very moist condion
+2.0	—	+2.9	unusual moist condition
+1.0	—	+1.9	moist condition
+0.5	—	+0.9	incipient moist condition
+0.4	—	(–) 0.4	near normal condition
(–) 0.4	—	(–) 0.9	incipient drought condition
(–) 1.0	—	(–) 1.9	mild drought condition
(–) 2.0	—	(–) 2.9	moderate drought condition
(–) 3.0	—	(–) 3.9	severe drought condition
below		(–) 4.0	extreme drought condition

Impact of Droughts

As referred to earlier, droughts affect all types of life-form in the biospheric ecosystem because both plants and animals directly depend on water. Any shortage of water supply adversely affects them. Thus, the impacts of prolonged droughts include ecological, economic, demographic and political aspects. Prolonged drought conditons in a given region change the biotic component of the natural ecosystem because (i) some species of plant and animals perish as they cannot withsand extreme drought conditons; (ii) some animals migrate to other places and hence there is marked decrease in the population of certain animal species; (iii) some animals die of hunger and starvation; (iv) there is stiff competition for food due to scarcity created by drought among the animals which result in the elimination of weaker animals etc. The most significant ecological impact of prolonged drought is natural control of plant and animal populations.

The **economic impact** of droughts includes economic losses due mainly to marked decrease in agricultural production, livestock yield and even industrial production because of short supply of water. **Demographic impact** of drought includes depopulation of regions/areas and temporary migration of affected people and animals. Many of the people of Sahelian region of tropical Africa have left the region because of persistent drought conditions. There is frequent migration of people from drought affected areas of Rajasthan, Gujarat, Maharashtra and Andhra Pradesh in India. Due to prolonged severe droughts for four consecutive years (1984 to 1987) in Gujarat and Rajasthan a large number of people temporarily shifted to Uttar Pradesh and Bihar together with their cattle though most of the people sold out their cattle at much lower prices due to total dearth of fodder. **Political significance** of extreme drought conditions includes the change of political power due to acute shortage of foodgrains caused by crop failure due to droughts (e.g. Mr Khurschev had to step down from power in the former USSR because he had to purchase wheat from the western world) and increase in the dominance of the USA, Canada etc. on drought affected poor countries because they have to depend on those developed countries which have surplus food supply. Even the fate of state and central government of India depends on the nature and mercy of monsoon rainfall.

Environmental impact : Continued dry spells for several years may change the nature of dryland ecosystems because prolonged drought causes **desertification** and **desert spread.** The drylands, in the absence of atmospheric and soil moisture, are subjected to severe wind erosion. Even the semi-arid ecosystem suffers most from prolonged severe droughts. The idea of impacts of droughts on human activities may be had from the detailed discussion of a few **case studies** of drought affected areas as given below.

(1) **Sahel Region** : The region extending between hot and dry desert areas of the Sahara in the north and the Savanna region in the south and running from the western part of Africa through Mauretania, Senegal, Mali, Upper Volta, Niger, Nigeria, Chad, Uganda, and Ethiopia in the east is called **Sahel Region** or **Sub-Sahara Region.** The drought zone of the Sahel is a tropical grassland and is characterized by a **feast and famine climate** wherin the life of nomadic herders and grain farmers exclusively depends upon rainfall received during a short rainy season. The growth of grasses depends

upon rainfall. Even the people of Sahel depends for their drinking water upon groundwater which is replenished through rainfall. Prolonged drought results in the depletion of groundwater and hence acute scarcity of drinking water. This region is very often frequented by severe droughts which cause extensive damage to flora and fauna and humans. The past severe droughts began in 1968 and continued upto 1975. The drought became acute during 1971 and 1972 and its cumulative effects became so disastrous that it became a **human catastrophe** by 1974. The prolonged drought for 7 years in continuation resulted in the depletion of subsurface water reserve and drying of water holes (trapped water in sands and gravels of stream beds) and low wells. The nomadic herders were compelled to sell out their cattle which could survive due to water shortage in the beginning of the drought and thus they became refugees and collected in special camps near the cities and towns to get small packets of foodgrains donated by other countries of the world. Inspite of relief measures coming from over the world thousands of people of the Sahel region died of hunger and staravation, thirst and diseases. About 5 million cattle were claimed by severe Sahel drought. About 50,000 people in Ethiopia alone died of starvation, malnutrition and diseases. The drought condition still persists in Ethiopia and millions of children are suffering from malnutrition and diseases.

(2) **Australia** : Drought is very common natural phenomenon in Australia. The Australian droughts are both frequent in recurrence and widespread in spatial coverage. A few case histories of droughts would certainly reveal the magnitude of Australian droughts. The worst drought started in 1895 and continued upto 1903. The adverse impacts of this prolonged droughts included sharp fall in the number of sheep from 106 million sheep in 1891 to only 54 million in 1902 and 50 per cent decrease in the number of cattle (from 14 million cattle in 1891 to 7 million in 1902). Several enormous dust storms submerged many fences under thick cover of huge amount of soils and sands, the city of Melbourne was drenched (on November 21, 1902) with dust, several towns in the interior part could not see the sun on that day (November 21, 1902) because of thick layer of dusts in the air, railway lines at many places were buried under thick deposits of loose soils and sands. Severe hazardous droughts again occurred during 1911-1916, and 1919-1920. Thus the three phases of severe droughts viz. (i) 1895-1903; (ii) 1911-1916 and (iii) 1919-1920 resulted in marked decrease in the agricultural land which was increased substantially after 1866. It may be pointed out that favourable rains during 1860's and 1870's led to phenomenal increase in the cropped area as the cultivated lands were extended from more favourable coastal areas to the inland marginal areas. The cropped land in the south-east Australia increased 6 times between 1866 and 1900 but the aforesaid three consecutive phases of severe droughts forced the farmers to retreat towards the favourable coastal areas. The recent severe droughts in Australia include two widespread dry spells in 1965-66 and 1967-68 which caused decrease in the farm gross national product by 20 per cent.

(3) The aforesaid examples of droughts are related to those areas whch are already rain deficient regions and droughts are very common features but there are other areas where there is no problem of large-scale droughts. In such areas a drought causes serious problems of various sorts. The example of 1975-76 drought in U.K. reveals this fact. The twelve-month period (from May 1, 1975 to April 30, 1976) recorded less than 60 per cent of normal annual precipitation. The dry conditions continued for further 4 months i.e. from May 1, 1976 to August 1976. This prolonged dry spell resulted into acute shortage of supply of water for domestic and industrial purposes as the reservoirs could not be filled up to their capacities. There was also substantial fall in agricultural production as wheat, barley, oats and potato productions in England and Wales fell by 22, 12, 12 and 13 to 40 per cent respectively. The total loss to agricultural production amounted to more than 500 million pounds. The gravity of the 1975-76 drought may be gauged from the fact that the government appointed a Drought Minister to handle the problem arising out of the drought.

(4) **India** : Since monsoon climate and associated rainfall is very much deceptive, irregular and uncertain, and hence nearly most parts of the country are affected by drought and floods in one way or the other. For example, Rajasthan is a chronic drought-prone area but heavy rainfall during the first two weeks of July 1990 (exceeding 500 mm a day) caused severe floods in most parts of Rajasthan. The chronically drought affected areas of the country include 67 districts where drought affects 25 per cent

of the total cropland and 12 per cent people of India. This zone, worst affected by severe droughts, includes larger tracts in the states of Rajasthan, Gujarat, Haryana, Maharashtra, Karnataka, Andhra Pradesh and southern Uttar Pradesh. The severe drought-prone areas of India are divided into 3 zones as follows :

(1) **Zone I** : Desert and semi-arid regions spread over an area of about 600,000 km^2 and form a rectangular tract which stretches from Ahmedabad to Kanpur (to form eastern and southeastern border), from Kanpur to Jullundhur (to form north-eastern and northern boundary) and form Jullundhar to Rann of Kutch along the western international border. The region is characterized by low rainfall ranging between 350 mm and 750 mm per annum but the extreme western desert areas receive even less than 350 mm of annual rainfall. This zone includes whole of Rajasthan and Gujarat, western and south-western parts of Punjab, most of Haryana, south-western part of Uttar Pradesh and narrow strip along the western and north-western border of Madhya Pradesh. There is little impact of droughts in Punjab and Haryana because sufficient irrigational facilities are available but the areas having no irrigational facilities are the worst drought-affected and famine areas of the country.

(2) **Zone 2** : The second chronic drought-prone zone forms a rectangular tract which spreads over the rainshadow areas of the Western Ghats. In fact, this zone is situated to the east of the Western Ghats and extends in a width of 300 km. It includes south-western Andhra Pradesh, eastern Karnatka (east of Western Ghats) and south-western Maharashtra (east of Western Ghats). This region covers 370,000 km^2 of area and is characterized by highly erratic mean annual rainfall of less than 750 mm.

(3) **Zone 3** : Besides the aforesaid two broad zones of severe droughts, there are some scattered pockets of droughts in the country such as Tirunelveli district located to the south of Vagai river, Coimbatore area, Palamau area of Jharkhand, Purulia District of West Bengal, Kalahandi region of Orissa etc. The scattered pockets of droughtprone areas cover about 100,000 km^2 of area.

The Ministry of Agriculture has identified drought affected areas in the country on the basis of rainfall distribution, frequency of occurrence of droughts and percentage of irrigation. On the other hand, the Irrigation Commission has demarcated drought-prone areas on the basis of rainfall and irrigation in the region concerned. Thus, according of the Irrigation Commission those areas are drought affected areas which have less than 1,000 mm of mean annual rainfall, 20 per cent or more of the years do not receive even 75 per cent of this annual amount of rainfall and where irrigated areas are less than 20 per cent of the cropped areas.

Drought Control Measures

Unlike floods, forewarning is not possible in the case of droughts, though computer-based study of numerous climatic and meteorological parameters may provide some idea about the nature and pattern of precipitation in the ensuing year. Even the amount of air moisture and precipitation may be increased through anthropogenic activities such as afforestation. The usual practice prevalent in most of the country to combat droughts is to provide relief measures to drought affected people. Such measures are also necessary because these provide immediate reliefs to the affected people. Besides, there should be long-term measures to ameliorate the severity of droughts. Such measures include afforestation to increase the content of air moisture, to increase the amount of precipitation, to increase the rate of infiltration of rainwater and hence the replenishment of groundwater and rise of water table; introduction of dry farming techniques to reduce the dependence of farming on rainwater; checking of desertification or desert spread; introduction of water conservation schemes; development of horticulture and pastures; revitalisation of Drought-Prone Area Programmes (DPAP); construction of reservoris, digging of wells etc.

20

ENVIRONMENTAL DEGRADATION

20.1 ENVIRONMENTAL DEGRADATION : MEANING AND CONCEPT

As stated earlier environment is a comprehensive term which in general refers to the surroundings but in geographical perspective environment includes abiotic or physical (land, air water) and biotic (plants and animals including man and his several functions, organizations and institutions) components of the life supporting layer-the **biosphere**. The dynamic evolving earth system in general and the biospheric system or natural environmental system in particular are governed by discernible processes, both physical and biological. Various physical, chemical and biological processes are continuously engaged in the creation, maintenance, and destruction of surface materials of the earth's surface (both organic and inorganic). These earth materials e.g. minerals, rocks, soils, water etc. are not only created but are also maintained, changed in their properties, transferred from one place to another and even destroyed by geologic cycle but these materials even while passing through the aforesaid pathways remain initially uncontaminated and are very useful for man but whenever these materials are used or dispersed by man, they become contaminated and are seldom available for human use because either they are dispersed to such locations which may not be reached by man for fairly long period of time or they become so contaminated that they are not reusable.

Physical and biological processes of the natural environmental system operate in such a way that any change in any part of the environment at any place in a specific time period is suitably compensated by negative feedback mechanism in a natural condition. Thus the natural environmental system has 'inbuilt self regulating mechanism' known as **homeostatic mechanism** through which any change in the natural ecosystem / environmental system is counterbalanced by responses of the system to the change and ultimately ecosystem stability or environmental equilibrium is restored. In other words, any change in the environment brought by the natural processes is suitably compensated by changes in other components of the environment. Thus there is reciprocal relationship between various components of the environment. The physical processes create suitable habitats for biological communities on the one hand, biological communities (mostly man) modify the environment on the other hand.

In fact, life has continued to modify and alter the atmospheric, lithospheric and oceanic components of the natural environment since the very beginning of life on this planet earth. The very nature of the atmosphere, the rocks and sediments, freshwater on the earth's surface and oceanic water in terms of organic and inorganic constituents has been greatly modified by the organisms including both plants and animals. Since the dawn of industrial revolution in 1860 man has emerged the most powerful environmental process spearheaded by modern technologies capable of modifying the environment to great extent. In fact, of all the organisms man is the most intelligent and powerful animal and is capable of not only affecting the environment like other organisms but is also able to alter the basic composition of the environment at a scale detrimental not only to all biota but also to his own existence. Phenomenal increase in human population in the present century has put enormous pressure on natural resources which has resulted into accelerated rate of rapacious exploitation of natural resources in order to meet out the demand of ever-increasing population, rapidly growing industries and increasing urbanization. The development of modern technologies and increased economic functions of man have further accelerated the rate of exploitation of natural resources. All these have modified a few of the components of the environment to such an extent that the adverse effects on the environment cannot be set right by the **homeostatic mechanism** or self regulatory mechanism of the environment. Consequently, the changed environmental conditions adversely affect the organisms (both plants and animals including man) in the biosphere.

Thus it is obvious that environmental degradation refers to the deterioration in its physical component brought in by the biological processes mainly by human activities to such an extent that it cannot be set right by the self regulatory mechanism or homeostatic mechanism of the environment.

In other words, environmental degradation simply means overall lowering of environmental qualities because of adverse changes brought in by human activities in the basic structure of the components of the environment to such an extent that these adverse changes adversely affect all biological communities in general and human society in particular. Environmental degradation leaves direct impact on the ecology and thus is caused ecological imbalance because of marked reduction in the ecosystem and ecological diversity. In fact, ecological imbalance is the indicator of environmental degradation because it becomes difficult to perceive environmental degradation directly in the initial stages. Adverse effects of environmental degradation are easily observable in biological communities.

20.2 ENVIRONMENTAL DEGRADATION AND POLLUTION

To most of the people environmental degradation and pollution are synonym as both are concerned with the lowering of the quality of the environment. But a distinction between these two aspects of the lowering and deterioration of the quality of the environment may be drawn on the basis of causative factors and scale of deterioration of environmental quality in terms of magnitude/intensity and covered area. To my mind environmental pollution means lowering of the quality of environment at local scale caused exclusively by human activities whereas environmental degradation means lowering of environmental quality at local, regional and global scales by both natural processes and human activities. For example, volcanic eruptions, earthquakes, submergence and emergence, faulting, atmospheric storms like cyclones (typhoons, and hurricanes), forest fires, atmospheric lightning, hailstorms, excessive snowfalls, geological erosion, landslides and avalanches etc. are the natural factors which cause destabilization of ecosystem and thus cause environmental degradation but natural processes absorb them and keep the ecosystem in balance.

It may be pointed out that many of the aforesaid natural factors are also affected by human economic and technological activities (the rates and magnitude of some natural factors may be increased or decreased by human activities). Even the scale factor may also be negated if we consider such human factors/actions which degrade the environment at global level. In other words, the adverse changes in the environmental quality at local scale are caused by human activities as referred to above and thus the lowering of environmental quality caused by human activities at local level is generally called **pollution** but some times the effects of human activities are so immense that the environment is degraded at global level as well. For example, depletion of ozone layer by human actions (release of chlorofluorocarbon, halons, nitrogen oxides etc.

in the stratosphere) and increase of **green house effects** of the atmosphere due to increase of concentration of carbon dioxide in the atmosphere through burning of fossil fuels in the factories may change the radiation balance of the earth and the atmosphere at global level. The nuclear holocaust disaster may change the global environment within the shortest time scale. It, thus, appears that environmental degradation and pollution may not be differentiated on the basis of factors and causes of the lowering of the environmental quality and the area affected by environmental changes.

It may be suggested that environmental degradation should be taken in wider sense so as to include both natural and human factors whereas **environmental pollution should be restricted to the lowering of environmental quality by human factors only in limited areas.**

A further area of distinction may be drawn between environmental degradation and pollution in terms of destabilization of various components of the environment. **Pollution may be restricted to include the adverse effects of human activities in one of the components of the environment or one group of the organisms** while environmental degradation may include total deterioration and degradation of the majority of the components of the environment/natural ecosystem and its organisms, both plants and animals.

Moreover, environmental degradation and pollution are always considered in terms of man. In fact, environmental degradation is a wider term which means disturbance of various magnitudes in the ecosystem equilibrium, environmental stability and ecological balance caused by human activities. When environmental degradation/deterioration crosses the critical limit to such an extent that it becomes lethal to the organisms in general and human beings in particular, it becomes pollution. **Thus pollution is the upper limit of environmental degradation/deterioration.**

Since the realization of environmental degradation and pollution has now become of global concern and there is growing awareness about pollution as **'vicious circle'** situation, a comprehensive study of various aspects of pollution is not only desirable but is also necessary for environmental geographers so that future strategies for resource utilization and comprehensive environmental management programmes may be formulated.

The comprehensive study of environmental degradation/deterioration and pollution includes perception of pollution (in terms of individuals, social problems, economic problems, and ecological problems); definitions of pollution; sources and types of pollution; causes and processes of pollution; environmental effects of pollution on humans, organisms and ecosystems; monitoring of pollution about programmes. These aspects shall be discussed in the next chapter (chapter 21).

20.3 TYPES OF ENVIRONMENTAL DEGRADATION

It is apparent from the preceding discussion that environmental degradation is much bigger and comprehensive term which includes lowering and deterioration of environmental quality caused by both natural factors (as elaborated in the preceding sections) and anthropogenic factors from local level through regional level to global level. The events caused by either natural processes or anthropogenic processes, which bring immediate changes in the natural environment and inflict colossal damage and loss to the environmental quality and living organisms are called **extreme events** or **hazards** which are further divided into two broad categories viz. (i) **natural hazards** (like tropical cyclones, volcanic eruptions, earthquakes, floods, drought etc.), and (ii) **anthropogenic hazards** (like nuclear holocaust, chemical war, etc.). The deterioration of environmental quality beyond a critical limit caused by human activities is called **pollution.** The environmental degradation/deterioration may be classified as given below :

Environmental Degradation

(Divided into two categories on the basis of factors responsible for the lowering of environmental quality and the level and magnitude of lowering/deterioration of environmental quality)

(1) Extreme events and hazards

(2) Pollution

Extreme events and hazards have been widely classified and discussed in chapter 17 of this book.

Pollution

(Pollution is caused by human activities and is generally divided into two broad categories).

(i) Physical Pollution

(Physical pollution is caused due to lowering of the quality of physical or abiotic components of the environment by human activities and is further divided into three subtypes).

(A) Land Pollution

Examples : (a) accelerated rate of soil erosion through rill and gully erosion, (b) desertification, (c) soil pollution, (d) salinization etc.

(B) Water Pollution

Examples : (a) pollution of sea water, (b) pollution of groundwater, (c) pollution of streams, (d) pollution of lakes etc.

(C) Air Pollution

Examples : (a) depletion of ozone layer, (b) increase in the concentration of greenhouse gases in the atmosphere, (c) decrease in the quality of air, etc.

(ii) Social Pollution

(Pollution caused in different aspects of the society due to cumulative effects of extreme events/hazards and pollution. Social pollution may be further divided into several sub-types).

(A) Population Explosion

(B) Sociological Pollution

Examples : (a) educational and social backwardness, (b) crimes, (c) perpetual quarrels, (d) wars, (e) communal riots etc.

(C) Economic Pollution

Example : poverty.

20.4 PROCESSES OF ENVIRONMENTAL DEGRADATION

It has already been stated that environmental degradation and pollution are always considered in terms of living organisms in general and human beings in particular. Though natural processes mainly extreme events also bring substantial changes in the natural environment but these changes are counterbalanced by the nature itself and no serious perpetual environmental and ecological problems crop up but when man augments the rate and magnitude of natural extreme events and hazards these become lethal to natural environment and serious environmental problems are generated due to large-scale environmental degradation/deterioration. Secondly, man also degrades the environment through his increased economic activities. Thus environmental degradation is effected in two ways viz. (i) through the augmentation and acceleration of extreme events and natural hazards by man, and (ii) through the exploitation of natural resources and their processing in a variety of ways by man.

In fact, the processes and mechanisms which disturb the stability or equilibrium of the environment and consequently cause environmental degradation are called the **processes of environmental degradation.** The stability of the environment means balance between the production and consumption of each element in the natural ecosystem. There is inbuilt self regulatory mechanism called **homeostatic mechanism** in a natural ecosystem through which any change in either of the components of the environment (abiotic and biotic components) and in production-consumption ratio of the elements caused by natural processes is counterbalanced and the stability of the environment and the natural ecosystem is maintained. When the environmental change brought in by the activities of man or say by anthropogenic processes is not suitably compensated by homeostatic mechanism of the natural environment, environmental degradation sets in. This so happens when the changes brought in the natural environment by anthropogenic processes are continuous and enormous and these changes exceed the resilience or the capacity of the environment to sustain these changes. For example, rapid rate of mass felling of trees in a forest ecosystem seldom allows regeneration of forest community because exposed land surface due to reckless deforestation is subjected to intense weathering and accelerated rate of erosion and thus rich fertile soils and nutrients are washed out by surface runoff. Himalayan forest ecosystem is a typical example of ecosystem/environmental instability because mass deforestation and subsequent overgrazing have resulted into complete removal of natural forests at certain localities.

It may be stated that there are mutual interactions between the abiotic and biotic components of the environment and the environment remains in equilibrium condition so long as the mutual interactions and relationships between the abiotic and biotic components of the environments are harmonious and these do not bring far reaching changes in any or many components of the environment. Man being the most intelligent animal of all of the animals and technologically most advanced tries to make use of the environmental resources and to make the environmental influences favourable for him. In doing so man affects and modifies the environment and thus environmental conditions are changed by human activities. When the environmental changes brought in by man exceeds the critical limit, environmental degradation starts. It may be pointed out that the factors and the processes responsible for the environmental stability or instability (and hence environmental degradation) should always be viewed in terms of resilience of the natural environment or natural ecosystem. If the environmental changes brought in by anthropogenic processes exceed the environmental resilience, environmental instability and hence environmental degradation is caused but when the environmental resilience is such that it can withstand the environmental changes, environmental stability is maintained and the natural environment is protected from being degraded.

The processes of environmental degradation are, thus, both natural and anthropogenic but anthropogenic processes are largely responsible for environmental degradation of high magnitude and of global concern. Man causes environmental instability and hence environmental degradation in the following manner :

- ➤ by destroying completely or partly the natural vegetation or original species or by replacing them by other vegetation or animal species,
- ➤ by introducing exotic plants or animals to any area where such biotic communities were not present previously,
- ➤ by altering or modifying one or more components of natural environment (land use changes, for example),
- ➤ by introducing foreign substances through the use of chemical fertilizers, pesticides and herbicides,
- ➤ by increasing or decreasing the original proportion of atmospheric gases,
- ➤ by manipulating environmental processes such as cloud seeding for induced precipitation, cloud dispersal, prevention of hailstorms etc.
- ➤ by altering chemical and gaseous composition of the atmosphere through industrialization and urbanization, etc.

Over-exploitation of exhaustible resources, continuation of exploitation of those natural resources whose reserves have reached a critical limit and are at verge of exhaustion, excessive use of those resources whose generation is a very slow process (like soils) etc. are few examples of rapacious use of natural resources by greedy economic man. Such human actions make the environment sick and degrade the environmental quality to such an extent that degraded environment endangers the very existence of human beings. In fact, the very existence of all living organisms depends upon natural environment. Clean air and water, fertile land, rich biotic community including both plants and animals, wilderness and recreational areas, sufficient mineral resources, ideal weather and climatic conditions etc. are the elements of the environments which are needed in sufficient amount for the maintenance and development of human society. 'Economic' and 'technological man' has started exploitation of natural resources at everincreasing rate inorder to meet the growing demands of the present-day human society. Thus man's exploitative and productive activities have significantly lowered the quality of life-saving clean air through expanding industrialization, urbanization and everincreasing means of transportation as the pollutants emitted from the human volcanoes (chimneys of the factories), house hold commodities and appliances, vehicles etc. have disturbed the natural gaseous composition of the atmosphere and global radiation balance.

Precious water resources, both surface water and groundwater, have been largely contaminated or being contaminated by industrial wastes, urban sewage, chemical fertilizers (released from the agricultural fields), toxic chemicals etc. The quality of fresh water all over the globe has been so degraded that these have become unsuitable for drinking purposes without being treated carefully before their use by the public.

Land has been degraded in almost all of the countries even in the tropical countries through accelerated rate of soil erosion by rill and gully erosion consequent upon rapid rate of deforestation. Large-scale deforestation has resulted into the decrease of infiltration of rainwater and therefore marked reduction in the recharge of groundwater and hence depletion in the groundwater resource. Marked increase in surface runoff; accelerated rate of soil erosion through rainsplash, rainwash, sheetwash and gully erosion; decrease in agricultural productivity and gross agricultural output; changes in weather conditions; increease in the frequency and magnitude of floods; marked decrease in the biological diversity of the natural ecosystem have caused overall disequilibrium in the natural environment and ecological imbalance. Land has been also degraded by unscientific mining operations and accumulation of huge amount of mining wastes and industrial and urban refuses. Several acres of good agricultural land on the right-bank of the Yamuna river opposite the city of Allahabad were rendered toxic and wasteland due to dumping of millions of tonnes of 'night soils' (human refuse) during the Kumbha Fair held at the confluence of the Ganga and the Yamuna rivers in the month of January, 1989 at Allahabad. (It may be stated that the confluence site at Allahabad, India, becomes the largest megalopolis of the world at least for a week during twelve-yearly Kumbha Fair as 20 to 30 million people congregate at the sacred confluence of the holy Ganga and Yamuna rivers at Allahabad).

Industrial expansion, sprawling urban growth, everincearsing tourism etc. have put enormous strain on wildeness areas and virgin natural areas hitherto unaffected by human influences. Now no wildareas or wilderness areas in true sense exist on this planet earth because man has reached every nook and corner of the planet earth. The present-day materialistic greedy economic man has spoilt the natural beauty of the environment through his exploitative activities.

It is now obvious that the anthropogenic processes, as referred to above (also see chapters 3 and 15 of this book), disturb the environment by changing the different components and thus the overall quality of the natural environment is lowered and environmental and ecological balance is disturbed. All these processes and after-affects lead to environmental degradation at local, regional and global levels.

20.5 CAUSES OF ENVIRONMENTAL PROBLEMS AND DEGRADATION

The 'environmental crisis' caused due to environmental and ecological changes is the result of developmental processes of the 'economic and technological man' of the past century. In fact, if the past century was marked by socioeconomic, scientific and technological development on the one hand, it was plagued by serious problems of environmental problems on the other hand. The environmental crisis arising out of the environmental degradation/deterioration caused by several forms of pollution, depletion of natural resources because of rapid rate of their exploitation and increasing dependence on energy consuming and ecologically damaging technologies, the loss of habitats due to industrial, urban and agricultural expansion, reduction and loss of ecological populations due to excessive use of toxic pesticides and herbicides and loss of several species of plants due to practice of monoculture and removal of habitats through forest clearance has now become of global concern. The life of common man is being so rapidly adversely affected by environmental degradation caused by man himself that 'there has been a marked growth of interest within the last decade in the quality of environment, the disruption of the earth's natural ecosystems and the depletion of resources. Pollution, ecology and environment have been projected from the cloistered world of science into the forefront of public debate, and all aspects of man's use of his environment have been widely discussed with passionate interest' (C.C. Park, 1980).

The most striking reason of the environmental degradation and hence global environmental crisis is the fast deteriorating relationship between man and environment because of rapid rate of exploitation of natural resources, technological development and industrial expansion. The rate of environmental change and resultant environmental degradation caused by human activities has been so fast and widespread that R.F. Dasmann (1976) has remarked that 'the human race is like an ape with a hand-grenade. Nobody can say when he will pull the pin' of the grenade and the whole world will be destroyed (in case of breaking out of nuclear war). J. Poelmans-Kirschen (1974) has recognized the following reasons for environmental degradation and resultant environmental crisis :

- Accelerated growth of production potential.
- Accelerated rate of scientific and technological discovery and development.
- Exponential increase in world population.

The impact of man on environment through his economic activities are varied and highly complex as the transformation or modification of one natural condition and process leads to a series of changes in the biotic and abiotic components of the environment. The impacts of man on environment fall into two categories viz. (i) direct or intentional impacts, and (ii) indirect or unintentional impacts. Direct or intentional impacts of human activities are pre-planned and premeditated because man is aware of the consequences, both positive and negative, of any programme which is launched to change or modify the natural environment for economic development of the region concerned. The effects of direct anthropogenic changes in the environment are noticeable within short period and these effects are reversible because both before and after studies of possible effects may enable the man to set the negative defects right to certain extent if so desired and intended. On the other hand, the indirect impacts of human activities on the environment are not premeditated and preplanned and these impacts arise from those human activities which are directed to accelerate the pace of economic growth, especially industrial development. The indirect impacts are experienced after long time when they become cumulative. The indirect effects of human economic activities may change the overall natural environmental system and the chain-effects some times degrade the environment to such an extent that this becomes suicidal for human being. (see chapter 3 of this book).

On an average, the environmental degradation and environmental crisis may be ascribed to the following factors :

- exponential growth in human population,
- accelerated pace of scientific and technological development,
- ambitious development projects aimed at fast economic development,
- fast expanding industries, sprawling urban growth and agricultural development,
- philosophical and religious outlook of the society,
- unfriendly behaviour of man with the natural environment,
- ignorance and lack of environmental perception and lack of public awareness towards environmental problems,
- economic poverty,
- affluence and richness,
- unscientific and illogical exploitation and utilization of natural resources etc.

20.6 RELIGIOUS AND PHILOSOPHICAL FACTORS AND ENVIRONMENTAL DEGRADATION

The teleological/religious approach to the understanding of the environment is based on the religious faith of man being superior to nature and all other creatures. This teleological school emanated from the teachings of Judo-Christian religious tradition which preached that 'man is superior to all creatures and every thing is created for his use and enjoyment.' This ideology of man-environment/nature relationship fostered the man to exploit natural resources and to subdue nature without considering the after-effects of reckless and uncontrolled plundering of natural resources. This religious but selfish faith of man-environment relationship led to excessive and rapid rate of rapacious exploitation of natural resources in North America and Western Europe as well as in other parts of the world which were their colonies. A host of scientific and environmentalists have held this religious tradition responsible for present-day environmental degradation and environmental/ecological crises.

The **'economic deterministic view point'** of the nature and the environment is also based on the basic ideology of man's mastery over environment and continued economic and industrial expansion through the application of modern technologies. 'The basic thesis of the growth (affluence) school is that because economic growth is required for political, social and economic stability, the 'quality of environment' normally assumes lower priority in formulating planning proposals and in long-term planning because the deterioration of the environment is generally protracted and socially less oblique than a deterioration in the economy' (C.C. Park, 1980). In fact, 'economic determinism' is based on two fallacious assumptions viz. (i) there are positive correlation between the population of a given region and the level of economic development and activity in that region, and (ii) the interactions of people, resources and society are governed by universal economic principle' (W. Zelinsky, 1966). Based on these two fallacious assumptions the 'economic determinism' believes in man's ability to solve environmental problems arising out of continued economic growth and industrial expansion. It may be pointed out that this extreme concept of economic determinism of the rich materialistic society led to rapacious exploitation of natural resources in the western developed countries and their colonies in Third World Countries and thus has created most of the environmental and ecological problems of global dimension.

The **'ecological viewpoint'** of the nature and the environment considers man as an integral part of the nature/environment and emphasizes symbiotic relationship between man and environment. In fact, this view point states that there should be harmony and not hostility between man and nature. This view point also lays emphasis on wise and restrained use of natural resources, application of appropriate environmental management programmes, policies and strategies based on ecological principles i.e. rational exploitation of natural resources and optimum utilization of natural resources.

20.7 DEFORESTATION AND ENVIRONMENTAL DEGRADATION

Forests are invaluable property of a nation because they provide raw materials to modern industries; timber for building purposes; habitats for numerous types of animals and micro-organisms; good friable and nutrient rich soils having high content of organic matter; offer protection to soils by binding the soils through the network of their roots and by protecting the soils from direct impact of falling raindrops; they encourage and increase infiltration of rainwater and thus allow maximum recharge of groundwater resources; minimize surface runoff and hence reduce the frequency, intensity and dimension of floods; they help in increasing the precipitation; they are natural 'sink' of carbon dioxide because they use carbon dioxide to prepare their food during the process of photosynthesis; they provide firewood to millions of people all over the world, and food and shelter to innumerable humans and animals. In fact, forests are 'life-line' of a nation because prosperity and welfare of the society directly depends on sound and healthy forest cover of a nation concerned. Forests are main component of the biotic components of the natural environmental system and the stability of the environment and ecosystem/ecological balance largely depend on the status of the forests of the region concerned.

It is a matter of serious concern that the present economic man has forgotten the environmental and ecological significance of natural vegetations mainly forests and grasslands and has destroyed the forests so rapidly and alarmingly that the forest areas at global, regional and local levels have so markedly decreased that several serious environmental problems such as accelerated rate of soil loss through rainsplash, sheetwash, rill and gully erosion; increase in the frequency and dimension of floods; greater incidence of drought due to decrease in precipitation etc. have plagued the modern human society. From ecological point of view, at least one third of the total geographical area of a country should be under rich forest cover but this general rule of environmental significance has been flouted in many of the countries. Deforestation has immediate adverse effects on soils and land because of exposure of ground surface to high intensity rainfall.

Many of the developing countries of the tropical and subtropical regions have lost substantial portions of their forest covers due to conversion of forested land into agricultural land in order to feed the teeming millions. India has also not been exception to the present global trend of rapid rate of deforestation. According to the Report of the Forest Survey of India, the following is the present status of different land uses under forest covers in India (table 20.1).

20.1 : Different categories of forest covers in India

Total forested area		11,45,816 km^2
Closed forest area		2,24,025 km^2
Open forest area		2,59,062 km^2
Degraded forest area		1,79,624 km^2
Good forest cover		4,83,123 km^2
Forested cover	20.2%	of the total geographical area of India
Good forest cover	6.8%	of the total geographical area of India
Open degraded forest	13.4%	of the geographical area of India

Source : Report of the Forest Survey of India.

Ecologically required forest cover = 33% of the total geographical area of the country.

Actual forest cover = 20.4% of the total geographical area of India.

Net required forest cover = 12.6% of the total geographical area of India.

According to the report of the Forest Survey of India as stated above the total forested cover is only 20.4 per cent of the total geographical area of India but this claim has been refuted by several sources based on satellite imageries and only 13 per cent of the total geographical area of the country has been reported under different categories of forest covers. If we believe the report of the Forest Survey of India as stated above 7,00,000 km^2 or 70 million hectares of land should be afforested so as to put 33 percent of the total geographical area of the country under forest cover as per requirement of the ecological principle. If this target is to be achieved in a period of 15 years, annual rate of afforestation should be 5 million hectares/year, but the present rate of afforestation is only 0.18 million hectares per year. It means that the present rate of afforestation must be augmented by 28 times to achieve the required target.

The rate of loss of forests in India may be gauged from the fact that there has been total loss of 91,70,000 hectares of forests within a short period of only 8 years (between 1972-1980). The major cause of rapid rate of deforestation in India is the increasing pressure of biotic communities including both human population and animals on our forest resources as with only 2 percent of the total land of the world India supports 15 per cent of the total world population of human beings and 13 per cent of the total number of cattle of the world.

See section 25.3 of chapter 25 of this book for latest information on forests and deforestation in India.

Causes of Deforestation

The major causes of deforestation at global and regional levels are divided into the following categories :

- conversion of forest land into agricultural land,
- shifting cultivation,
- transformation of forests into pastures,
- overgrazing,
- forest fires,
- lumbering,
- multipurpose river projects,
- biological factors etc.

(1) Land Use Changes

Increasing population growth at fast rate mainly in the developing countries has put enormous pressure on forested land because it becomes necessary to clear the virgin forest covers and convert them into agricultural land so that agricultural production may be substantially increased and food may be provided to hungry human population. This trend has resulted into large-scale destruction of savanna vegetation in the subtropical regions. Rich and extensive grasslands of Russian 'steppes', American 'prairies', South American 'pampas', South African 'Velds' and New Zealandean 'Downs' have been extensively converted into agricultural farms and these areas have now become major grainaries of the world. Extensive forest covers of the Mediterranean areas have been converted into horticultural farms. The same is the story in the majority of the countries of south and south-east Asia.

(2) Shifting (Jhuming) Cultivation

Shifting cultivation is major cause of forest loss in the hilly and mountainous areas of south and south-east Asia. The loss of virgin forest cover due to shifting cultivation is increasing every year in the different parts of India as is evident from table 20.2.

Table 20. 2 : Annual rate of loss of forest cover due to shifting cultivation in India

Provinces	Area affected by shifting cultivation in square kilometers per year	Population dependent on shifting cultivation (000)
Orissa	5298	706
Meghalaya	760	350
Nagaland	730	400
Arunachal Pradesh	703	270
Assam	700	403
Mizoram	600	260

Manipur	500	300
Andhra Pradesh	173	116
Tripura	170	100
Bihar	162	61
Madhya Pradesh	81	114
Kerala	19	16

Source : Report of the Forest Survey of India.

(3) Transfromation of Forests into Pasture

Transformation of forests into pastures has been responsible for rapid rate of loss of virgin forests in the Mediterranean and temperate areas mainly in North America, South America and Africa. The main factor behind large-scale conversion of woodland into pasture land is expanding dairy farming and cattle ranching for meat. Extensive areas of original forest stands in New England region, Michigan and mountainous states of the Western U.S.A.; Canada, South American countries and African Savannas have been converted into pastures for cattle ranching.

(4) Overgrazing

Overgrazing of forests of moderate cover by animals mainly in the tropical and subtropical and arid and semi-arid areas has resulted into large-scale degradation of natural vegetation, if not the complete destruction of forests. Very low yielding (low per capita yield of both meat and milk) but large numbers of cattle in the developing countries of the world have consumed most part of the ground cover and bushes and herbaceous plants. The deforested areas have been worst affected by grazing animals because no fresh regeneration of plants has been allowed by large herds of grazing animals. The Savanna grasslands have been completely destroyed partly by conversion of grasslands into agricultural farms by man and partly by overgrazing.

(5) Forest Fires

Forest fires whether natural or man-made are effective destroyers of forest covers. Atmospheric lightning is the major source of natural forest fires. Besides, man causes forest fires through his intentional/advertent and unintentional actions. Deliberate burning of vegetation to get rich and fresh grasses next season leads to several types of changes in the surface materials. The herdsmen also throw burning 'bidies' (smoking sticks used mostly in South Asian countries particularly in India, Pakistan, Bangladesh and Sri Lanka) inadvertently which causes forest fires. Besides destroying vegetations, forest fires harden the ground surface which decreases the porosity of the soils and consequently there is little infiltration of rainwater. Thus most of the rainwater becomes effective surface runoff which accelerates the rate of soil erosion. Secondly, the frequent forest fires destroy the leaf litters on the ground and thus the soil nutrients and humus contents are markedly reduced and some times are completely destroyed. Besides, forest fires kill all of the micro-organisms living in the leaf litters mainly decomposers and in the soils and plant roots. Thus forest fires not only destroy natural vegetation and retard and taboo regeneration of trees but also cause tremendous damage to the biological communities and thus cause ecological imbalance.

(6) Lumbering

Lumbering for domestic and commercial purposes is the real cause of large-scale destruction of forest covers. Everincreasing demand of timber for various purposes due to industrial expansion, urban growth and rapidly increasing human population has done great damage to natural forest covers all over the world. The reckless felling of trees from the very beginning of the 20th century without caring for environmental and ecological consequences and without having any plan for replanation to ensure regeneration of forests has depleted the forest resources to such an extent that the possible gruesome consequences of deforestation are looming large over the human society all over the globe and even the existence of human beings stands threatened. Collection of fodder and firewood by rural population from the depleted and poor forest covers mostly in the developing countries has further degenerated already impoverished forest covers.

The private contractors in collusion and connivance with the government officials in India and many developing and even a few developed capitalist countries have done great damage to the natural forest covers through reckless felling of trees for their limited economic gain at the cost of national interest. Inspite of the provision of Forest Policy in force since 1894 and implementation of National Forest Pollicy since 1952 and despite the guidelines issued by the Union Government of India for not diverting the forest area to non-forestry uses there has been remarkable loss of 91,70,000 hectares of good forest area in India between 1972 and 1980. This colossal loss of precious ecological resource despite the guidelines issued by the Government of India that forest area should not be converted into other forms of land uses and in case of any inescapable diversion (of forest land to non-forestry uses) it should be done with the concurrence of the states and the loss of forests be adequately compensated by providing, as far as possible, equivalent alternative land for afforestation and reforestation, clearly indicates the non-compliance of the government directives by the government officials and greedy and selfish contractors. Developmental projects such as construction of dams, reservoirs and canals and mining operations are damaging even the dense and extensive rainforests of the Amazonia. The local people mainly Indian aborigins have raised their arms against the destruction of forests (16 to 20 million hectares per year) because their habitats, livelihood and even their existence have been threatened.

(7) Multi-Purpose River Projects

Multi-purpose river projects require larger areas to be submerged for the storage of huge volume of water in the reservoirs constructed behind the dams. Thus submergence of forested riverine areas completely destroys the natural forests. Tehri Dam Project on the head-waters of the Ganga, and Narmada River Project in Madhy Pradesh and Gujarat, India, were under serious public protests. Tehri Dam on the headwaters of the sacred Ganga river, in Garhwal Himalaya, Uttarakhand, India, is meant to generate hydroelectricity to meet out the growing demand of power in Uttar Pradesh and adjoining states and Union Territory of Delhi but its construction was frequently stopped because of protest by noted environmentalist and **chipko movement** leader, Bhat and Sunder Lal Bahuguna. It is feared that storage of millions of acre feet of water in the reservoirs behind Tehri Dam will submerge hundreds of square kilometres of forested land which will destroy rich forest cover and displace local inhabitants. It is also feared that if the dam breaks in, for which there is every likelihood because the Tehri Dam is being constructed in the lower Himalayas which come under maximum seismic intensity zone, Rishikesh (an important holy pilgrim centre on the bank of the Ganga) will be flooded in 57 minutes and Hardwar (another important holy piligrim center) in just 63 minutes. It is believed that in case of sudden breach in Tehri Dam major cities on either side of the Ganga in its downstream section in the alluvial plains of Uttar Pradesh will be submerged within 72 hours. Similarly, there was strong protest from general public to abandon the proposed projects of Sardar Sarovar and Indira Sagar on Narmada river in the states of Madhya Pradesh and Gujarat, India. The ecologists believed that the submergence of thousands of sequare kilometres of areas would destroy regional forest covers and animal community and thus would cause serious environmental and ecological problems.

It may be mentioned that inspite of continued protests from environmentalists and activists now the Tehri Dam Project and Sardar Sarovar Project have been completed and they have started generating hydel power.

(8) Biological Factors

Biological factors also help in destroying the natural vegetations. Conversion of forest areas into agricultural farms has resulted into marked shrinkage in the forest covers and thus tremendous pressure of animals on existing forests. Further more, application of chemical fertilizers, pesticides and herbicides in the agricultural fields nearer to the forests has driven out micro-organisms such as insects and termites towards the adjoining forests where these cause serious damages to the plants.

Adverse Effects of Deforestation on Environment

Deforestation gives birth to several problems encompassing environmental degradation through accelerated rate of soil erosion, increase in the sediment load of the rivers, siltation of reservoirs and river beds, increase in the frequency and dimension of floods and droughts, changes in the pattern of distribution of precipitation, intensification of greenhouse effects, increase in the destructive force of the atmospheric storms etc; economic loss through damages of agricultural crops due to increased incidence of floods and droughts, decrease in agricultural production because of loss of fertile top soils, decrease in the supply of raw materials to the industries and building materials (timber) to the urban and rural areas, marked decrease in fodder to animals etc. and social problems in the form of economic poverty, crimes and increased legal litigation.

As already stated forests are natural umbrella for ground surface because these protect the ground surface from erosion caused by falling raindrops and control radiation balance of the earth and the atmosphere by consuming increased amount of carbon dioxide released from everincreasing 'human volcanoes' (chimneys of the factories) and thus prevent the earth from becoming too hot. Removal of forest cover exposes the ground surface to the atmospheric processes. It may be pointed out that forests intercept falling raindrops and thus split them and reduce their (of raindrops) kinetic energy. Intercepted rainfall reaches the ground surface slowly in the form of **'aerial streamlets'** through the leaves, branches and stems of trees. Thick leaf litters on the ground surface after decomposition provide humus content to the soils and also make the soils friable. Thus the ground surface allows maximum infiltration of rainwater and minimum surface run off. On the other hand, deforestation exposes the ground surface to falling raindrops with full kinetic energy. This results into maximum erosion of soils because the infiltration of rainwater is markedly reduced and surface runoff is increased. Thus deforestation causes a chain of effects which adversely affect the natural environmental conditions as given below.

Accelerated rate of soil erosion through rainsplash, rainwash and sheetwash, rill and gully erosion consequent upon deforestation increases sediment load of the rivers. Increased suspended and bedloads of the rivers cause rapid rate of siltation of alluvial rivers which results in gradual rise of the river beds. Thus increased surface run-off and reduced water accommodating capacity of the river valleys due to siltation increase the frequency and dimension of floods of alluvial rivers as flood waters easily overtop the river banks and spread over larger areas.

It is supposed that decrease in vegetation cover mainly forest cover reduces precipitation but no significant studies at global and regional levels have demonstrated positive correlation between deforestation and decrease in the amount of average annual precipitation. Deforestation also results in the increase of the concentration of carbon dioxide in the atmosphere because forests consume carbon dioxide during the process of photosynthesis for the manufacturing of their food but absence of forests allows more concentration of carbon dioxide in the atmosphere because of its non-consumption. It is, thus, obvious that deforestation increases greenhouse effect of the atmosphere which raises the temperature of the earth's surface and the atmosphere.

Increased rate of soil erosion caused due to deforestation results in colossal loss of fertile topsoils and agricultural land which ultimately causes marked reduction in agricultural production. Rapid rate of rill and gully erosion in the intervening zone between the Ganga plains and the foreland of Indian peninsula has resulted into the conversion of thousands of hectares of good land into ravinous land which has displaced the affected inhabitants from their agricultural land. The development of circuitous network of dense mesh of gullies ranging in depth from a few metres to 80 m has rendered vast expanse of agricultural and forest land into waste land on the one hand and has deprived millions of people of their livelihood on the other hand. Thus the increased rate of soil erosion consequent upon deforestation and destruction of grassland has been responsible for social pollution in addition to land degradation. The zig-zag network of deep gullies of the riverine tracts of the Yamuna, the Chambal, the Betwa rivers etc. (Fatehpur, Etawa, Agra, Banda, Jhansi, Jalaun districts of Uttar Pradesh and Bhind, Morena, Gwalior, Tikamgarh, Chhatarpur districts of Madhya Pradesh, India) offers easy and safe shelter to dacoits and bandits. This has alarmingly increased the rate of crimes including theft, dacoity and murder in the said areas and thus has degraded the social atmosphere.

Deforestation has also increased the rate of aeolian erosion through deflation and desertification through desert spreads. Many of the tribal areas of the forested land of India have lost the forest stands in their immediate surroundings and thus are facing the acute problem of fuels and fodder. The destruction and alteration of habitats due to deforestation causes ecological imbalance in the region concerned.

CONSERVATION MEASURES

The protection and conservation of forest resources are not only desirable but are also necessary for the economic development of a nation and maintenance of environmental and ecological balance from local through regional to global levels. Forests conservation measures include (i) protection of remaining forest covers, (ii) increase in the forest cover so as to cover 33 per cent of the total geographical area of a country by forests through afforestation in the open wasteland and reforestation of already deforested areas particularly in those deforested areas which are not suitable for cultivation such as mountainous and hilly areas. Integrated Conservation Research (ICR), an ecological group of U.S.A., has launched massive programmes of forest conservation in collaboration with UNESCO's 'Man and Biosphere (MAB) Programme'. The ICR has demonstrated that the rianforests are more valuable if used on a sustainable basis than if they are cut down for immediate short-term profit of a few selected elites and affluent class of society. The findings of ICR have shown that about 50 per cent of the world's tropical and sub-tropical forests have already disappeared because of unchecked reckless felling of trees. The main goals of the ICR's programme of forest conservation in the developing countries of the tropical and substropical areas are (i) to protect the species diversity that exist in the tropical and sub-tropical forests, and (ii) to expand the forest land under government protection.

Selective felling instead of mass felling of trees according to the justified demand may save unnecessary destruction of valuable forest resources. It is very interesting to note that generally main cause of the rapid rate of destruction of tropical rainforest is assigned to the increasing demand of timber by industrialized countries but according to UNESCO's report only about fifteen percent of the felled trees are exported to the developed and industralized countries. Though the demand is more for certain species of trees only but unfortunately hundreds of species of trees of lesser values are destroyed to get access to the desired expensive trees. In the process the building of roads and clearance of forests for having spaces for loading areas and logging camps destroy larger tracts of forests without any use.

The first and foremost task to conserve forests is to protect the existing forest from merciless reckless cutting of trees by greedy economic man. This task may be achieved through government legislation and by arousing public interest in the importance of the forest resources. Majority of the countries have their national policies on forests and there are provisions for some legislations against deforestation but even then forests are being destroyed at faster rates. This is because of the fact that the contractors achieve their selfish ends in connivance with the government officials.

The National Forest Policy of India has also laid down certain basic principles for proper management and conservation of the forest resources of the country as follows :

- ➤ classification of forests according to functional aspects into protected forests, reserved forests, village forests etc.
- ➤ expansion in the forest cover by planting trees in order to ameliorate the physical and climatic conditions for the welfare of the people,
- ➤ provision for ensuring progressive increasing supplies of fodder for animals and timber for agricultural and domestic uses and firewood to local inhabitants nearer to the forests,
- ➤ opposition to reckless extension of agricultural land at the cost of forest land,
- ➤ extension of forest area by massive plan of tree plantation on a large-scale at war footing so as to bring 33 per cent of the country's geographical area under forests etc.

Though there is strict guideline from the Government of India that forest should not be diverted to non-forestry uses and in case if the diversion of forested area to other forms of land uses is necessary and unavoidable (such as construction of dams and reservoirs, installation of industrial plants, construction of houses, roads etc.) it should be done with the approval and concurrence of the state government and the loss of forests due to their diversion to other forms of land uses should be suitably compensated by planting trees in other proportionate areas but this guideline is seldom followed either by the government machinery or private sector. Recently, the government has banned the cutting of green trees by the public without having prior permission of the government. This law does not allow a person even to cut down his own trees in the premises of his house or in his agricultural farm without the permission from appropriate government authority.

It appears that directive principles and laws alone cannot guarantee safeguard of forests from their destruction but mass public opinion against the adverse effects of mass felling of trees is also necessary to check onslaught of the forests. Relentless efforts of Sundarlal Bahuguna, a noted environmentalist from the hills of the Uttarakhand Himalaya (India) and his followers culminating into the **'chipko movement'** (sticking to the trees while contractors try to chop the trees) and the movement of domestic women of Reni, Uttarakhand (India) are a few examples of mass awakening of public opinion in favour of economic and environmental significance of natural forests and their concern against adverse effects of their destruction. It may be stated that about 90 percent of the women in the developing countries depend on land for their survival because they grow the crops, gather the fodder, fuel and firewood, fetch the water, look after the animals and perform all other domestic duties while men mostly go to the plains for earning their livelihood. Similarly, the women of Reni, Uttarakhand (India) were completely dependent upon natural environment (forests, water, land etc.) and suffered some of the most serious problems of the environmental degradation caused by forest removal on a large-scale. After observing silently the loss of fertile soils due to slow poisoning of land through soil erosion, drying of several springs which supplied drinking water, decrease in rainfall, dearth of firewood and fodder and destruction of terraced farms due to increased surface runoff etc. caused by deforestation they (women of Reni) realized the importance of nature and the extent of link between environmental degradation caused by deforestation and economic poverty. The depletion of natural resources such as loss of firewood and fodder, drying out of streams and springs, depletion and contamination of ground water aquifers has direct bearings on women folk because they have to walk over longer distances to gather firewood and fodder, to collect water for domestic uses etc.

All these enabled the women of Reni to understand and realise the value of the forests on which they depended. They realised that forests protect watersheds, maintain water springs and groundwater, regulate water flows, ensure constant supply for pure water, protect their agricultural land and ultimately maintain ecological balance. Thus awakened by far reaching adverse consequences of environmental degradation caused by deforestation the women of Reni, of Uttarakhand, rose in revolt against mass felling of trees and reckless deforestation. They resisted the cutting of trees and reckless deforestation. When the contractors refursed to oblige them and stepped forward to chop down the trees in their forest, they resorted to fast, gherao and even wrapped themselves around the trees (resorted to **'chipko movement'** started by Bhat and Sundarlal Bahuguna). The wrath and axes of the contractors could not deter them from their firm determination because they knew fully the nature and gravity of the battle they were waging against the powerful contractors who had the blessings of big political bosses and government officials. 'Hugging the trees was a symbol of their ultimate survival. Their symbolic message to halt deforestation has been carried on foot to the farthest Himalayan peaks and has spread throughout the range. Padyatras (march on foot) have been undertaken by **'chipko'** activists over thousands of miles'.

Thus the movement against the destruction of natural forests undertaken by the women of Reni of Uttarakhand Himalayas (India) has awakened the general public of India and of the world towards the importance of natural forests for maintaining the environmental (natural) and ecological balance. They started plantation of oak trees in their deforested land because they knew that oak trees would provide the basis for water, fodder and fertilizers and would help in maintaining the environmental balance and ecosystem stability of their hill region. Small 'Mahila Mandals (women's groups) are now organizing the tree planting in hundreds of villages and protecting trees on community lands. They are introducing improved cooking stoves and biogas programmes are being implemented for fuel conservation. The message of the movement started by the women of Reni and the popular **'chikpko movement'** (initiated by Bhat) of noted environmentalist Sundarlal Bahuguna and his followers have reached different parts of India. Similar movements are being organized by several groups of environmentalists of voluntary organizations and some forceful and effective environmental slogans have awakened the local public such as 'Save the Western Ghats', 'Save the Ganga and the Himalayas' (launched by Sundarlal Bahuguna against the construction of Tehri Dam on the upper reaches of the Ganga at Tehri town), 'Save the Narmada watersheds and their ecology' (launched by Baba Amte) against the implementation of Narmada Valley Project and the construction of Sardar Sarovar (reservoir) and Indira Sarovar in Madhya Pradesh and Gujarat, India. The messages of the movement of the women of Reni have also crossed the Indian border and reached the women folk of African and Latin American countries who have many of the problems and hardships as experienced by the women of Reni. They have also started movement against the destruction of forests. For example, widespread movement has been started against the destruction of forests through the expansion of mining activities, giant muti-purpose projects in the rainforests of the Amazon basin. It is evident that the people themselves may become environmental mediators, guardians and protectors of natural forests if their sentiments are aroused for the conservation and protection of natural forests.

The second important measure of effective conservation of natural forest is to adapt scientific and judicious method of cutting of trees by following selective approach. In other words, only mature and desired trees should be cut and unwanted trees of low economic value should be avoided. It may be pointed out that cutting of mature trees is also ecologically desirable because the old saying 'use them or loose them' holds good because if mature trees are not removed they will automatically perish and may damage other trees.

The third significant measure of forest conservation is to cover more and more wasteland and already deforested land with forests through vigorous planning or afforestation. The afforestation programmes must be based on the principle of plantation of multi-species of trees rather than single species of trees because biotic diversity is ecologically more significant than mono-culture. Secondly, ecologically sound trees should be given more preference than the commercial trees at least in the areas of fragile environment. For example, deforested areas of the Himalayas are being planted with more pine saplings than oak because of commercial purposes. The main purpose behind vigorous planting of pine trees is to obtain resin but oak is environmentally more sound than pine because relatively larger leaves of oak trees make thick ground leaf litters which after being decomposed enrich the soils by producing humus and more organic content. Thus the humus-rich soils become friable and contain more moisture. Such soils allow rich undergrowth of other varieties of plants and thus provide habitats for numerous varieties of animals and micro-organisms. Thirdly, only those trees should be given preference under the scheme of afforestation which are suitable for the local environmental conditions. For example, planting of eucalyptus trees (an exotic species) on large-scale almost in all parts of India is not advisable because eucalyptus is suitable for certain combinations of environmental conditions only such as 'tarai' region of India. Further more, eucalyptus is not of much ecological and environmental significance because of less branching, small size of leaves, fewer number of leaves and long roots. Fourthly, forests should not be replaced by commercially important fruit orchards. For example, cultivation of apples in many parts of the Hiamalayas in general and Himachal Pradesh (India) in particular has done great damage to the original stands of natural forests. Apple cultivation causes deforestation in two ways viz. (i) Apple cultivation requires clearance of land from vegetal cover, and (ii) Huge quantity of wood is required for packing of apples every year. According to an estimate the clearance of forest for apple cultivation accelerates the rate of soil erosion by 250 times of normal rate of soil erosion. It has been estimated that one hectare of apple farm damages 7 to 10 hectares of forests.

The Integrated Conservation Research, an U.S. ecological research group, has suggested elaborate programmes for the betterment of forests. These programmes include (i) agroforestry, (ii) ethnobotany, and (iii) natural history-oriented tourism.

20.8 AGRICULTURAL DEVELOPMENT AND ENVIRONMENTAL DEGRADATION

Agricultural development in terms of expansion of agricultural land, increase in agricultural productivity and net agricultural production due to development of modern scientific techniques, advanced technologies, increased production and use of chemical fertilizers, expansion in irrigational facilities, development of high-yielding varieties of seeds etc. has solved the problem of growing demand of food due to everincreasing world population on the one hand, it has also created or is creating hazardsous environmental problems of serious concern on the other hand. Though the pace of agricultural development has to be maintained if we do not want to let the teeming millions die of hunger but environmental degradation should also not be allowed to continue due to agricultural development because it would also cause irreparable damage to human society. Thus the modern 'economic' and 'technological man' is at the cross road of dangers in all directions. If population goes on increasing we have to go for agricultural development so that production is increased to feed the population though in doing so we would be preparing a time-bomb for our own destruction.

The agricultural development degrades the environment in a variety of ways e.g. (i) through the application of chemical fertilizers and pesticides and insecticides, (ii) through the increase in irrigational facilities and amount of irrigation, (iii) by making changes in biological communities etc.

The phenomenal increase of population of the world mainly of the developing countries causes increase in the demand of food supply which can be met only through (i) increase in the agricultural land and extensive cultivation, and (ii) increase in the productivity of agricultural land and thus intensive cultivation. Increase in agricultural land is usually possible by felling the trees and converting the forest land into agricultural land. Conversion of forest land into agricultural farms on slopy ground causes accelerated rate of soil erosion. The increased rate of soil erosion caused by deforestation for increasing agricultural land to increase the food supply in view of increasing population causes chain effects on environmental conditions in the affected areas as well as in the far off regions e.g. deforestation causes soil erosion which causes loss of fertile top-soils and thus decreases productivity, soil erosion increases sediment load of the rivers which causes siltation and rise of the river beds which results in the reduction of water accommodating capacity of the river valleys which thus increases the frequency, magnitude and dimension of floods which damage agricultural crops in the flood plain areas.

The replacement of forest by fruit orchards also degrades the environment of forest biome/ecosystem. Though the conversion of temperate grasslands of the Russian 'Steppe', North American 'Prairies', South American 'Pampas', South African 'Veld', New Zealandean 'Downs' etc. has done great service to humanity by solving the immediate problem of food supply because they have now become the grainaries of the world but this process has also disturbed the ecological balance of the said regions because monoculture system has been responsible for the dispersal of a large number of animal species as well as extinction of many animal species. Similarly, the conversion of virgin Mediterranean woodlands into vineyards and horticulture farms and pasture has destroyed the natural vegetation on a large-scale and has caused loss of soils due to accelerated rate of erosion. Shifting cultivation in many tropical and subtropical countries has consumed millions of square kilometres of natural forest covers. It is evident from table 20.2 that about 10,000 km^2 area of forested land is deprived of its natural forests every year in India because of practicing of shifting (jhuming) cultivation. Cultivation of potatoes on the hillside slopes cleared of natural dense forest cover in Mehgalaya and Assam (India) has though increased the production of potatoes which are widely used in the north-eastern hill states of India but has also caused accelerated rate of soil erosion because potato cultivation offers least protection to the soils against high intensity rainfall. Extensive deforestation due to tea plantation, shifting cultivation and other sedentary forms of farming in the north-eastern hill states of India has damaged the environment to large extent through increased soil erosion, modification in weather and climatic conditions and ecological imbalance.

Replacement of forest cover by apple cultivation in the hill districts of Himachal Pradesh and Uttarakhand, India or say practicing of monoculture in place of biotic diversity of forest ecosystem tells the story of adverse impact on the environment of the Himalayas. Apple cultivation has enormously increased in Himachal Pradesh in the post-independence era at the cost of rich natural vegetation of the Himalayas (falling in Himachal Pradesh). It may be stated that at present Himachal Pradesh produces about one third of the total apple production of India. Though the apple cultivation has increased the economic prosperity of the state to some extent but it has swallowed large area of natural forest covers. Lured by the economic gain of apple cultivation the farmers removed the forest at accelerated pace and started apple plantation. Apple cultivation results in complete removal of all natural vegetations because no other plant is desirable in apple fields. Normally, the apple plants start yielding fruits after 5 to 7 years of their plantation. During this period of growth of apple plants the open areas between them are devoted to potato cultivation which allows more and more soils to be eroded because potato plants are totally unable to bind the soils and to protect them from the high intensity rainfall. This results in the removal of fertile and valuable top-soil layer through soil erosion caused by rainsplash, surface and rillwash. Secondly, monoculture in the form of apple cultivation also causes ecological imbalance because most of the plants and animals and micro-organisms are destroyed. Thirdly, a lot of wood is required for the packing of apples. This aspect places further pressure on forests and consequently more and more trees are cut in order to manufacture wooden boxes for the packing of apples and their export. According to an estimate wood of about 7 to 10 heactares of forests is required for the packing of apples of one hectare of land. Fourthly, huge amount of fungicide (chemicals to destroy pests) is used to save the apples from the dangerous disease of scab. This toxic dangerous chemical finds its way to surrounding areas and streams via surface runoff, rills and rivulets and thus contaminates the waters of the hills as well as of the plains.

Continuous intensive cultivation to get increased production of crops from the same farms also result in decrease in the productivity of the soils because there is critical limit of every type of soil beyond which no increased production can be sustained inspite of increased use of chemical fertilizers. It may be remembered that continuous cultivation of cotton in the piedmont region of the Applachians in the south-eastern U.S.A. since the colonization of the U.S.A. by the British settlers has resulted into marked decease in the fertility of the soils because of increased rate of soil erosion through the ploughed furrows and the saturation of the soils due to their excessive use. This resulted into marked reduction in the quality as well as in the total production of cotton due to substantial decrease in the productivity of the soils. Evidences of soil degradation due to excessive intensive cultivation have also been received from Punjab, the agriculturally most advanced state of India.

The phenomenal increase in agricultural production in India since 1960 under the programme of Green Revolution due to application of advanced farm techniques, modern scientific methods and technologies, increased irrigational facilities, increased use of new hybrid and high-yielding variety of seeds and chemical fertilizers and pesticides and herbicides has no doubt made India self-reliant in the matter of food grains but simultaneously agricultural development has also created a few serious environmental problems which must be taken note of and remedial measures must not only be searched out but also must be implemented before these problems become out of control. Large-scale application of synthetic chemical fertilizers no doubt enriches the soils by providing additional amount of nutrients which help in quick and maximum growth of agricultural plants but these plants cannot make use of all of the chemical nutrients supplied in the form of synthetic chemical fertilizers by man. Thus the unused chemicals continue to accumulate in the soils. The amount of unused chemicals in the soils goes on increasing every year. This high concentration of chemicals in the soils pollutes them. These chemicals are also eluviated (downward movement) in the lower horizons of the soils and are moved further downward with the percolating rain and irrigational water to join the groundwater. Thus the chemicals not only pollute and degrade the soils and their different horizons but also contaminate groundwater which is used for irrigational and domestic drinking purposes. This is called **agricultural pollution** (pollution of land and water due to accumulation of unused chemical fertilizers applied to the crops for increasing agricultural production).

Increased use of pesticides, insecticides and herbicides to control epidemic diseases of crops, to kill undesirable and harmful insects and to destroy unwanted weeds in the agricultural fields also contaminates the soils, the water and even the fruits and grains and thus harms human beings because these synthetic chemicals reach human bodies via fruits and grains.

Continuous use of ammonium sulphate as chemical fertilizer to boost the agricultural crops results in the increase of the concentration of sulphate ions because ammonium ions are largely consumed by the crops but sulphate ions are left unused. The increase in the concentration of sulphate ions in the soils makes them acidic. Similarly, increased use of potassium nitrate and sodium nitrate results in the high concentration of potassium and sodium ions respectively. The nitrates are partly washed out by the surface runoff and are brought to the lakes, ponds and streams and are partly moved downward with percolating water.

Thus groundwater and surface water are heavily contaminated and polluted. The downward movement of nitrates is a very slow process. It takes about one year to reach the depth of one or two metres of soils and ground layer. Nitrates unconsumed by crops in the field take about 50 years to reach the deepest aquifers and groundwater storage. In fact, slow but gradual accumulation of toxic chemicals in the underground environment is hidden chemical time bomb which may explod any time and may cause unimaginable damage to man himself who is the creator of such chemical bombs. These would be chemical bombs being formed just below the surface we live on may be neutralized either by reducing the use of chemical fertilizers and pesticides, insecticides and herbicides or through heavy watering of the agricultural fields. But there is greaer risk of coming out of these unused toxic chemicals due to heavy watering of crops because heavy watering would reuslt in marked rise in the level of groundwater table and the toxic chemicals, which have moved downward with the percolating water, would now come upward with rising water table and thus would damage crops, other plants, micro-organisms, animals and man who would use contaminated water. The organisms cannot escape from using the contaminated groundwaters because these chemicals would also contaminate surface water, soil-moisture and soil-water and even the fresh waters of the ponds, lakes and the rivers because toxic chemicals would reach these water bodies through surface runoff.

Some of the toxic chemicals mainly nitrates reach our bodies through vegetables and foodgrains wherein chemical reactions may transform nitrates into such forms which may cause cancer. It may be stated that this may be only a possibility because it has not been substantiated as yet by the scientific and medical experts. It is not only desirable but is also necessary to limit the use of chemical fertilizers and to increase the application of natural or biofertilizers (prepared from the wastes of animals and herbaceous plants) so that the production level of crops may not only be maintained but may also be raised.

The transport of chemical fertilizers from the agricultural fields through surface runoff increases the concentration of nutrients in the ponds, tanks, lakes and rivers. This increase of rich nutrients causes phenomenal growth of a few plants, the process known as **'eutrophication'** in the inland water bodies and rivers while it causes death of the other plants and animals and micro-organisms. This processes results in the pollution of lakes, ponds and rivers and adversely affects the BOD (biological oxygen demand) of the waters.

Increased agricultural production consequent upon increased demand of food supply due to phenomenal growth in human population demands increased facilities for irrigation. Further more, the application of chemical fertilizers to increse the agricultural production also requires heavy watering of crops several times in a single crop season. Thus green revolution in India has resulted into marked increase in irrigated lands through pumpsets, tubewells and canals besides traditional means of irrigation like well and tank irrigation. Heavy watering of agricultural field mainly by canal irigation causes waterlogging whch results in salinization wherein salt contents move upward due to capillary action and accumulate on the top layer of the ground surface. Thus accumulation of excessive salt contents in the soils causes **'usarisation'** (conversion of fertile land into wasteland due to accumulation of salt layer on the top layer of the soil profile) which renders the agricultural land wasteland and thus makes the once fertile soil sterile one. The process is very much active in the canal irrigated areas of India. For example, a sizeable area of good agricultural land in Rajasthan has been adversely affected by salinization due to heavy watering from Indira Canal. Canal waters also pour down huge amount of silt and sands which decrease the fertility of the soils.

It may be summarized that agricultural production has to be increased inorder to meet the increasing demand of food supply due to everincreasing population of the world in general and of the developing countries in particular. Increased agricultural production means increase in agricultural land at the cost of destruction of forest and consequent soil erosion, substantial increase in the productivity of land through the practice of intensive cultivation, increased use of machines and modern scientific techniques, application of chemical fertilizers, pesticides, insecticides and herbicides, increase in the frequency and area of watering of agricultural fields etc. All these processes and measures of increased agricultural development cause several serious enviornmental problems such as deforestation and related problem of soil erosion, increased sediment load of the rivers, siltation of river beds and increase in the frequency and dimension of floods; pollution of soils through chemical fertilizers and pesticides, insecticides and herbicides; contamination of groundwater and surface waters; salinization of soils due to heavy watering from canal irrigatin etc. It appears that the root-cause of all these environmental problems arising out of agricultural development is the increase of human population at alarming rate. So the foresmost step to be taken is to stop population growth because if population continues to grow agricultural development has to be maintained.

20.9 POPULATION GROWTH AND ENVIRONMENTAL DEGRADATION

To most of the people growth of human population at alarmig rate is the most significant cause of the lowering of environmental quality and ecological balance. In fact, there are conflicting ideas and views regarding the exact principal cause of environmental degradation wherein the lowering of envrionemtnal quality and ecological imbalance have been assigned to overpopulation, or to the failures of the social system or to modern technologies. The **'pro-population school'** is of the opinion that the growth of world population at exponential rate is the only reason of environmental degradation while other reasons are offshoots of the factor of over-population. For example, industrial expansion, urban growth, agricultural development, increase in means of transport and communication etc. are the results of population growth because the people must generate better facilities for their existence and better life. The development of scientinfic techniques and advanced technologies has to be done in order to save the humanity from hunger and natural calamity and disaster. Thus it is obvious without doubt that overpopulation is the root cause of environmental degradation and ecological imbalance.

Everincreasing population places greater demands on the finite resources of the earth. The rate of exploitation of natural resources increases more rapidly than the rate of population growth. This has caused and is causing exhaustion of certain valuable non-renewable resources. It is desirable to know some of the characteristic features of world population before assessing the impact of population growth on the environment.

➤ The rate of incrase of the world population has been so rapid since the prehistoric period to the present time that the period required for the doubling of the size of the world population has constantly decreased. The estimated world population doubled on an average after every 1500 years between 8,000 B.C. (when the population is estimated to have been around 5 million) and 1650 A.D. In fact, the world population increased by hundredfold between 8000 B.C. and 1650 A.D. (estimated world population being about 500 million). It required 200 years for the world population to double its size from about 500 million (470 million) in the year 1650 to about 1000 million (1091 million) in the year 1850. The next doubling of the size of the world population was accomplished in still lesser time as the world population doubled its size from 1000 million in 1850 to 2000 million in the year 1930 that is only in a period of 80 years. Again the size of the world population was doubled from 2000 million in 1930 to 4000 million in 1975 thus taking only 45 years. It is estimated that the world population will require just only 36 yeas to double from 4000 million to 8000 million (around 2015 A.D.) if the population of the world coñtinues to grow by a rate prevalent in 1970 (Kamla Gupta, 1983 in L.R. Singh et.al. 1983 and P.R. Ehrlich, et. al. 1970).

Table 20.3 : Estimates of world population

Years 1	World Population (in millions) 2	Year 3	World Populaton (in millions) 4
8000 B.C.	5	1920	1,811
14 A.D.	266	1930	2,070
350	254	1940	2,295
600	237	1950	2,513
800	267	1955	2,745
1000	280	1960	3,027
1200	384	1965	3,344
1340	378	1970	3,678
1500	427	1975	4,033
1650	470	1980	4,415
1750	694	1985	4,830
1800	919	1990	5,275
1850	1,091	1995	5,733
1900	1,571	2000	6,199

Source : (i) 8000 B.C. estimate; (ii) figures for 14 A.D. to 1340 A.D. are estimates; (iii) figures for 1500 A.D. to 1600 A.D. from C. Clark, 1967; (iv) for 1650 to 1900 A.D. from the United Nations Department of Economic and Social Affairs, Population Division, 1953; (v) for 1920 from the U.N. Demographic Year Book, 1962; (vi for 1930 and 1940 from the U.N. Demographic Year Book, 1969, and (vii) for 1950 to 2000 A.D. from World Population Trends and Prospects by Country, 1950-2000; Summary Report of the 1978 Assessment (United Nations Publicaton ST/ESA/SER, R/33).

➤ It is evident from table 20.4 that the average annual rate of increase of the world population was slow upto 1950 when the world population increased at the rate of 0.8 percent per annum. The most spectacular increase in the world population occurred during 1955-65 at the rate of 2.0 percent per year which resulted in the net increase of population by 600 million which was equivalent to the total world population upto the year 1700. The estimated rate of population growth per annum denotes a decreasing trend between 1965-70 (1.9 per cent per annum) to 1995-2000 A.D. (1.6 per cent per annum).

Table 20.4 : Average annual rate of Increase of population (percentages)

Period	World	Developed Regions	Developing Regions
1990-1950	0.8	0.8	0.9
1950-1955	1.8	1.3	2.0
1955-1960	2.0	1.3	2.3
1960-1965	2.0	1.2	2.4
1965-1970	1.9	0.9	2.3
1970-1975	1.8	0.8	2.2
1975-1980	1.8	0.7	2.2
1980-1985	1.8	0.7	2.2
1985-1990	1.8	0.6	2.1
1990-1995	1.7	0.6	2.0
1995-2000	1.6	0.5	1.8

Developed Regions include North America, Japan Europe, Australia, New Zealand and Russian Federation

Developing Regions include Latin America, China, East Asia, South Asia, Malanesia, Micronesia and Polynesia.

Source : World Population Trends and Prospects by Country, 1950-2000 : Summary Report of the 1978 Assessment (United Nations Publicaton, ST/ESA/SER, R/33).

➤ There is marked variation in the spatial distribution of population in the world. The concentration of population in urban centres mainly in metropolises and megalopolises and the developing regions of the world has sharpened the skewed distribution of the world population (table 20.5). It is evident from table 20.5 that underdeveloped and developing regions of the world accounted for about 70 per cent of world's total population in 1950 which increased to 72.9 per cent in 1975 and was expected to increase to 79 per cent by 2000 A.D. It may be pointed out that the rate of growth of population has declined sharply in the developed regions of the world (table 20.4) since 1965 while it has been very high in the developing countries. The result of uneven distribution of world population is great pressure of population on natural resources in few areas which causes lowering of environmental quality and causes ecological imbalance. Similarly, everincreasing concentration of population in the urban centres causes slums and environmental degradation and pollution. Increaseing urbanization also results in marked reduction in arable land and therefore in food production. Increasing urbanization also results in the siphoning of resources from the rual areas to the urban areas which causes economic imbalance. This resultant economic imbalance causes economic and social pollution.

Table 20.5 : Uneven distribution of world population (In million)

Year	World	Developed Regions	Developing Regions
1950	2,513	832	1,681
1955	2,745	887	1,858
1960	3,027	945	2,082
1965	3,344	1,003	2,341
1970	3,678	1,050	2,628
1975	4,033	1,093	2,940
1980	4,415	1,131	3,284
1985	4,830	1,169	3,661
1990	5,275	1,206	4,069
1995	5,733	1,240	4,493
2000	6,199	1,272	4,926

Source : World Population Trends and Prospects 1950-2000 : Summary Report of the 1978 Assessment (United Nations Publicatons, ST/ESA/SER. R/33).

Table 20.6 : Projection of world population (in billion)

Year	World Population at low fertility (one child per woman)	World Population at medium fertility (2 children per woman)	World Population at high fertility (3 children per woman)
2050	7.7	9.4	11.2
2100	5.6	10.4	17.5
2150	3.6	10.8	27.0
2200	—	11.0	—

Source : Population Division of the UN Economic and Social Affairs Department, 1998.

Table 20.7 : Regional pattern of future increase in population from 1995 to 2150 A.D.

Region	Population in 1995 (in billion)	Future Population 2150 (in billion)
Africa	0.7	2.8
China	1.2	1.6
India	0.9	1.7
Rest of Asia	1.3	2.8
Latin America and Caribbean Region	0.477	0.916
Europe	0.728	0.595
U.S.A. and Canada	0.297	0.424

Source : Prediction by Population Division of the UN Economic and Social Affairs Department, 1998.

It is evident from the above discussion that the rapid rate of concentration of world population, everincreasing concentration of population in the urban centres, rapidly increasing gap between the populations of the developed and developing regions of the world, increasing proportion of urban-rural population etc. are the basic and root causes of all sorts of environmental degradation and ecological imbalance because increase in population means more exploitation of natural resources which means inauguration of new environmental problems. It is, thus, necessary to control the world population to improve the environmental quality.

Overpopulation also results in economic poverty becuase all the resources are utilized to meet the bare necessity of the people. This results in unbalanced exploitation of natural resources. For example, poor countries (with large population) of the tropical regions are selling out their precious natural forest resources to developed countries. In the process there is rapid rate of loss of tropical rainforest per year. The economic condition of Brazil forces it to export huge quantity of wood of its rainforest to developed countries and Amazonia is losing 5 million hectares of its rainforest every year. The rapid rate of exploitation of natural resources in most of the developing countries of Latin America, Africa and South and South-East Asia in order to balance their foreign trade has changed large areas of natural landscape into vast wastelands and thus has caused several severe environmental problems such as accelerated rate of soil erosion, floods, droughts, etc.

20.10 INDUSTRIAL DEVELOPMENT AND ENVIRONMENTAL DEGRADATION

Industrialization due to advancement in science and technology started in 1860 in England and soon spread over western Europe and North America. No doubt, rapid rate of industrial development has given economic prosperity to human society, has given new dimension to socio-economic structure and has provided material comfort to the people of industrially developed countries but it has also created many-fold environmental problems. In fact, the glittering effects of industrialization has so greatly affected the mind of the general public that industrialization is now being considered as the parameter of modernity and as a necessary element of socio-economic development of a nation.

In the beginning several countries of western world blindly followed the race of industrialization and did not care for its adverse impacts on their own natural enviornment. Rapid rate of industrialization, thus, resulted into rapid rate of exploitation of natural resources and increased industrial output. Both the components of industrial development e.g. exploitation of natural resources and industrial production have created environmental degradation and ecological imbalance at global, regional and local levels in a variety of ways. Exploitation of natural resources in order to meet the industrial demand of raw materials has resulted into the following :

- reduction of forest cover due to reckless felling of trees,
- excavation of land for mining purposes,
- reduction in arable land due to industrial expansion,
- lowering of groundwater table due to excessive withdrawal of groundwater,
- collapsing of ground surface due to withdrawal of mineral oil and groundwater etc.

Development in agricultural sector in order to supply raw materials to factories such as sugarcanes (for sugar industry), cotton (for cotton textile industry) etc. has been responsible for over-utilization of soils which has resulted into soil pollution due to excessive use of chemical fertilizers and pesticides and insecticides.

Besides desired production, there are numerous undesired outputs from the factories such as industrial wastes, polluted water, toxic gases, chemical precipitates, aerosols, ashes and smokes etc. which pollute air, water, land, soils etc, and thus degrade the environment. The industrialized countries have increased the concentration of pollutants emitted from the factories in the air, water and land to such an extent that they have degraded the environment to the critical limit and have brought the human society on the brink of its destruction.

The industrial development, directed to accelerate the pace of economic growth, though may be economically significant but the after-effects are certainly socially undesirable. The immpacts of industrialization of the environment are not immediately noticeable because of time-lag as the effects of slow rate of changes (in some cases changes are rapid ones) of moderate nature in a few components of the environment and the cumulative effects of these changes after crossing the sensivity of the environment/natural ecosystem become hazarodous to human society. The adverse effects of industrialization may change the overall character of natural system and the chain effects some times become suicidal for human society. Majority of the impacts of industrialization are related to pollution and environmental degradation.

The release of toxic elements into the environment/natural ecosystem through the application of chemical fertilizers, pesticides and insecticides (output of chemical industries) changes the food chains and food webs and physical and chemical properties of soils. Similarly, the release of industrial wastes into stagnant waters of ponds, tanks and lakes, and into rivers and seas contaminates water and causes several diseases and deaths of aquatic ecosystems (e.g. washing and dumping of tailings or waste sludges form factories, release and concentration of specks of asbestos, release of mercury in its toxic methyl form, leakage of crude oil from oil tankers and resultant oil slicks on sea water, release of lead, mixing of different quantities of dissolved inorganic matter etc. are a few exmaples of industrial source of pollution which degrade the natural environment).

Increasing industrial expansion is responsible for the release of enormous quantities of pollutants (e.g. ions of chlorine, sulphate, bicarbonate, nitrate, sodium, magnesium, phosphate etc.) through sewage effuents into the rivers and the lakes and thus for contaminating the water. "The basins of rivers flowing through thickly populated and industrially developed regions (and there are almost all the rivers of the U.S.A., Japan and European countries, including two-third of the rivers in the European part of the former USSR) have long lost and water-main systems of sorts, and at the same time, have changed into sewers' (E.K. Fedorov, 1983). The tanneries (151) of Kanpur city (India) are heavily polluting the Ganga by discharging 5.8 MLD (million litres per day) of untreated effluents.

Release of several gases, smokes, ashes and other aerosols from the chimneys of the factories adversely affects the environment in a number of ways. The burning of hydrocarbon fuels (coal and petroleum) has increased the concentration of CO_2 in the atmosphere and thus has changed the natural gaseous composition of the atmosphere. The natural gaseous composition of the atmospheric CO_2 was fixed at 0.029 per cent or 290 ppm (part per million) before the start of Industrial Revolution (1750 A.D.) but the atmospheric level of the concentration of CO_2 has inccreased to 368 ppm (0.0368%) by 2000 A.D. and may further increase to 405-460 ppm by 2025, 445-640 ppm by 2050 and 540-970 ppm by 2100 A.D. if no sincere efforts are made to stabilize the CO_2 emission at 1990 level..The increase in the concentration of CO_2 content of the atmosphere may change global radiation and heat balance by increasing the level of sensible heat in the atmosphere because CO_2 intensifies the greenhouse effect of the atmosphere as CO_2 allows more absorption of outgoing longwave terrestrial radiation and thus more counter-radiation towards the earth's surface.

Release of chlorofluorocarban in the atmosphere through the operation of spray-can dispensers, refrigerators, airconditioners and fire extinguishers is capable of depletion of ozone layer. Depletion in ozone layer means less absorption of ultraviolet solar rays and thus substantial increase in the temperature at the earth's surface. Thus changes in the global radiation and heat balance caused due to increase in the concentration of CO_2 in the atmosphere and depletion of ozone layer may cause changes in weather and climatic conditions at global and regional levels, may cause severe damages to plant and animal lives and thus may cause ecological imbalance, may cause dangerous diseases like skin cancer etc.

Release of toxic gases through advertent and inadvertent actions of man causes environmental hazards which destroy all types of life-forms in the affected areas. The Bhopal Gas Tragedy (December, 3-4, 1984, India) and Chernobyl nuclear disaster (Ukraine) (1986) are a few examples of disastrous effects of modern industralization. The leakage of poisonous mic gas (methyl isocynate) from the Bhopal based Union Carbide Plant in the first week of December, 1984 killed more than 4000 people (though the official figure is 2500). Acid rains, urban smogs, nuclear holocaust, nuclear winter etc. are other forms of environmental hazards emanating from industrialization.

20.11 URBANIZATION AND ENVIRONMENTAL DEGRADATION

Increasing concentration of population in urban centres and origin and expansion of new urban centres due to industrial expansion and development are responsible for rapid rate of exploitation of natural resources and several types of environmental degradation and pollution in the developed and developing countries. The level of urbanization in the developed countries of the world has already reached its peak. The accumulation of wealth and availability of more economic and job opportunities in the urban centres have resulted into the concentration of population in the congested meteropolitan aras and thus the formation and growth of big slum areas. It is evident from table 20.8 that there has been rapid rate of urbanization since 1950. The percentage of urban population to total population was 29.0, 52.5 and 16.7 for the whole world, developed regions and developing regions respectively during 1950. The rate of urbanization was so rapid between 1950 and 1980 that within a span of 30 years the percentage of urban population to total population increased from 29.0 to 41.3 for the whole world (an overall increase of 12.3 percent), from 52.5 to 70.2 in the developed regions (an overall increse of 17.7 per cent) and from 16.7 to 30.5 in the developing countries (an overall increase of 13.8 per cent).

It is estimated that the percentage of urban populatin to total population would be 51.3, 78.8 and 43.5 for the whole world, the developed regions and the developing regions respectively. According to the Indian Censue of 1981 the urban population was 22.45 per cent of the total pupulation of the country. The density of urban population of India is 3000 persons per square kilometer whereas the density of rural population is only 160 persons per km^2. It was estimated that the urban population of India would be equal to the total population of the U.S.A. by the end of 20th century. Previously towns and cities were considered to be the centres of higher standard of life becuase of the better living conditions but now most of the urban centres of the developed countries in general and of the developing countries in particular have become unsuitable for human beings because of marked lowering of environmental quality due to phenomenal increase in the level of air, water and noise pollution, crowded streets and roads, slums, increasing trend of murder, theft, dacoity and other crimes etc.

Table 20.8 : Urban population of the world

Area	Size of urban 1950	population in millions 1975	1980	2000
World	724	1561	1807	3208
Developed Regions	449	794	834	1092
Developing Regions	275	794	972	2116
Percentage of Urban Population to Total Population				
World	29.0	39.3	41.3	51.3
Developed Regions	52.5	67.5	70.2	78.3
Developing Regions	16.7	28.0	30.5	43.5

Source : World Population Trends and Prospects by Country, 1950-2000 : Summary Report of the 1978 Assessment (United Nations Publication, ST/ESA/SER, R/33).

In fact, increasing urbanization means phenomenal increase in the concentration of human population in limited space which results in the increase of buildings, roads and streets, sewage and storm drains, pucca surface area, vehicles (motor cars, trucks, buses, motor cycles, scooters etc.), number of factories, urban wastes, aerosols, smokes and dusts, sewage waters etc. which cause several environmental problems. For example, increasing population of the urban centres uses enormous amount of water for various purposes. The used waste water like sewage water, if untreated, pollutes the streams and lakes because the urban effluents are allowed to be drained into them. The Yamuna river at Delhi has, in fact, become a sewage as 323 million gallons of sewage water enter the Yamuna per day through 17 open drains, while the capacity of all treatment plants of the Municipal Corporation of Delhi (MCD) is only 184 MGD (million gallons per day). 'Before the Yamuna enters the capital, 100 milliliters of its waters contain more than 7500 disease causing bacteria but after receiving Delhi's share of sewage it carries 24 million bacteria according to pollution control expert (N.I.P., Feb. 20, 1989). The tanneries (more than 151 in number) of Kanpur City (India) are heavily polluting the Ganga by discharging 5.8 MLD (million litres per day) of untreated water. The Ganga has been so heavily polluted at Kanpur because of urban and industrial effluents that the river water has become unsuitable even for bathing purposes. Many big cities located at the bank of the Ganga such as Kanpur, Allahabad, Varanasi, Patna, Kolkata etc. have heavily polluted the river through the disposal of sewage waters into the rivers.

For example, 346 outfalls of sewage drains of Calcutta Metropolitan Area dump 52 million gallons of waste water per day into Hooghly river from domestic sources and more than 100 million gallons per day from industrial sources.

Urban centres when combined with industrial sectors become more hazardous from the standpoint of environmental degradation and pollution. Huge quantity of aerosols and gases is emitted from human 'volcanoes' and vehicles which form 'dust domes' over the cities. These **'dust domes'** cause **'pollution domes'** over the cities. The urban and industrial growth has resulted into rapid rate of deterioration of the quality of air because of heavy pollution of air through gases and areosols emitted from the vehicles, factories and household appliances. About 60 per cent of the pollution of India's capital city of Delhi is contributed by vehicles. There were more than one million vehicles in 1989. It may be stated that the number of vehicles in the metropolitan area of Delhi increases by 95,000 per year. According to estimate of 1989 one million vehicles of Delhi metropolitan area spew the following pollutant daily (i) 20 tonnes of carbon monoxide which causes respiratory problem in human bodies; (ii) 400 tonnes of hydrocarbons which cause respiratory and heart diseases, hydrocarbons reach the upper air over the city and causes pollution dome; (iii) 6 tonnes of sulphur dioxide which causes sulphuric acid and falls as **acid rain;** (iv) large quantities of **suspended particulate matter** (SPM) including dust, flyash etc,; (v) 600 kilograms of lead which cause several diseases such as impairment of the nervous and respiratory system, mental retardation etc. According to Ashish Kothari, an environmentalist, 'pollution in Delhi has increased by 75 per cent over the last decade and its SPM level of 300 micro-gram per cubic meter of air is double the sefety limit set by WHO.'

The introduction of CNG-operated vehicles and metro-railways in Delhi has brought down air pollution considerably.

Kolkata an Mumbai metroplitan areas have also reached high level of air pollution. 'It has been found that emissions weighing 1305 tonnes including highly injurious elements are released into the atmospehre of C.M.D. (Calcutta Metropolitan District) area every year. Out of the total quantity of pollutants, about 900 tonnes are generated in the industrial belt of Calcutta and the rest in Howrah industrial belt. Among the pollutants, the suspended particulates constitute about 43.4 per cent (569 tonnes), carbon monoxide 33.4 per cent (450 tonnes), sulphar dioxide 9.1 percent (123 tonnes), hydrocarbons 8.7 per cent (102 tonnes) and oxides of nitrogen 5.3 per cent (70 tonnes). Suspended particulates are the predominant pollutants in the area of 140 km^2 of the metropolitan area (C.M.D.) where their concentration is the highest in the country. About 370 tonnes of dust are daily deposited in the city. It is also indicated that industries contribute 46.3 per cent (600 tonnes) of emissions followed by transportation which accounts for 27.2 per cent (360 tonnes) of emission, thermal power plants 14.7 per cent (195 tonnes) and domestic emissions 11.8 per cent (150 tonnes) (B.B. Singh in L.R. Singh et al. 1983). According to the Survey Report of the National Environmental Research Institute, Nagpur, India, the level of air pollution in Delhi, Kolkata, Mumbai, Chennai, Ahmedaba, Cochin, Hydrabad, Jaipur, Kanpur, Nagpur etc. has gone up. The industrial cities such as Mumbai and Kanpur register higher level of air pollution as the air has become highly polluted and toxic. The danger of acid rains because of increasing proportion of oxides of nitrogen and sulphur in the air is increasing. It is found that the level of sulphur in the air over Indian cities is very high. About 1700 pollutants are mixed with the air every day over Mumbai meteropolitan area. Out of these 55 per cent are emitted by the vehicles. The polluted air in Mumbai causes chest pains, cough, irritation of eyes, and respiratory problems.

Industrial towns and cities often cause poisonous killer urban smog due to trapping of pollutants mainly smoke and sulphur dioxide spewed from the chimneys of the mills by stagnant air during inversion of temperature. Such poisonous smogs occur over only those cities and towns which have factories and mills. The examples of poisonous smogs of Donora, Pennsylvania, U.S.A. (October 26, 1948, 43 per cent of the population became ill while 20 persons died), of Meuse Valley, Belgium (December 1950, 63 deaths) and of London (1952, 4000 deaths) are sufficient enough to demonstrate the killer effects of urban smogs caused by urban and industrial pollution.Increasing incidence of dense fogs and smogs over the cities causes hurdles in the transport systems.

Increasing urbanization also modifies the water budgets of surface water as well as groundwater. Increasing urbanization increases the frequency and dimension of floods of nearby streams because the convering of ground surface by pucca structure reduces infiltration of rain water and increases surface run-off. Moreover, the masonary storm drains quickly dispose off surface runoff of nearby streams. Urban centres also modify the local and regionl radiation and heat balance through the creation of **heat island** and **pollution dome** (see chapter 13, section 13.11).

Increasing urbanization increases pressure on groundwater resources for the supply of waer for domestic and industrial uses. Excessive withdrawal of groundwater rsults in the formation of large cavities below he ground surface. The development of such cavities causes the collapse of ground surface and thus inflicts great damage to human health and wealth. The example of Brooklyn (Kings County, New York, U.S.A.) is sufficient to demonstrate environmental impact of groundwater withdrawal. The pumping of water from beneath the ground surface of Brooklyn city for urban dwellers at the rate of 75 million gallons per day resulted into the formation of large cavity (5 miles wide and 35 feet below sea level) beneath the city. The saline water leaked into the cavity and the wells became contaminated due to saline water which forced the city authorities to close down these contaminated wells. The cases of land subsidence due to withdrawal of groundwater have occurred in several localities and cities all over the world e.g. Houstan (Taxes, U.S.A. subsidence of land by 0.3m to 1.0 m), Mexico city (subsidence of ground surface from 4m to 7m between 1891 and 1959), Venice (Italy) etc.

Besides industrial wastes from industrial cities, huge quantity of urban solid wastes also creates environmental problems. It may be pointed out that greater attention is paid towards the production, storage, accumulation, transportaton, treatment and proper disposal of urban wastes in the developed coutnries but the problem of urban wastes in the developing countries is difficult one because (i) no proper attention is paid towards the storage, transportation, treatment and proper disposal of solid wastes, (ii) the big cities of developing countries have grown out of unplanned old cities and towns and hence there are no facilities like wide road and streets for the operation of modern machines to clear the wastes, (iii) people do not care to stock the wastes at marked places etc. The quantity of urban solid wastes is rapidly increasing with urban expansion and growth in urban population. According to the report of the National Enviornmental Research Institute, Nagpur (India) daily production of urban wastes in Mumbay and Kolkata is 0.5kg per person whereas it is 0.15 to 0.35 kg per person per day for other Indian cities. Stinking heaps of garbage stay for several days as the municipal corporations are not very particular in removing these garbages. Besides stinking odour, these garbages of waste materials also contaminate water and air of urban areas. Urban centres also cause noise pollution of various magnitudes.

20.12 MODERN PRODUCTIVE TECHNOLOGY

Technological development has been a key factor in the development of human society right from stone age to the present century but the earlier technologies were less destructive because the main emphasis was to provide minimum requirements for the sustenance of life whereas the modern technologies have become more destructive because these are meant for accelerated rate of exploitation of natual rsources and their production into various forms to raise the material standard of human beings. In fact, the development of modern technologies based on intensive scientific researches and discoveries is closely associated with the philosophy of **'growth affluence school'** which lays more emphasis on maximum exploitation of natural resources, optimum level of production, rapid rate of economic development and significant rise in the material growth of human society. This 'growth or affluence school' of the industrialized western world has ben responsible for total revolution in the scientific researches and the development of sophisticated technologies to augment the production processes.

The modern technologies have now entered every aspect of economic, political, academic and social spheres of human society such as agricultural development through improved methods of cultivtion, hoeing, sowing, irrigation, harvesting, and the application of high yielding varieties of seeds, chemical fertilizers and pesticides and insecticides; industrial development through the development of highly advanced and sophisticated and most efficient machines, computers and complete automation, quick and efficient exploitation of natural resources, development of efficient and quick means of transportation (all belonging to economic spheres); development of fast moving vehicles like tanks, supersonic war jet planes, ships etc, manufcturing of deadly weapons such as atom and hydrogen bombs, nuclear warheads, intercontinental ballistic missiles, chemical bombs etc. (all related to political sphere); development of computer and several types of audiovisul aids, aerial photogrpahs and satellite imageries etc (related to academic sphere); development of numerous types of luxury goods such as refrigerators, innumerable cosmetic goods, supersonic jets, airconditioned motor cars etc. (related to social sphere).

The development of modern technologies has definitely created most of the present-day environmental problems. 'Environmental crisis is thus the inevitable result of a counter-ecological pattern of productive growth. The environmental problems are held to be associated with productive processes concentrating on synthetic and non-biodegradable material (such as the increased use of plastics and detergents rather than with radical changes in the overall output of goods or in material aspects of consumption' (C.C. Park, 1980).

A few examples may reveal the curse of modern technologis as given below :

➤ Man through advanced scientific techniques is capable of modifying the weather conditions for his benefits. For example, man modifies weather by **cloud seeding** to stimulate clouds and induce precipitation through crystalization of supercooled drops through the application of solid carbon dioxide and certain compounds of iodine. 'A few hundred grams of solid carbon dioxide or a few grams of iodine compound are enogh to crystallize a cubic kilometer of supercooled cloud of water drops' (E. Fedorov,)

➤ Man is able to prevent hailstorms. Such practices are being carried out in Russia, Bulgaria, Hungary, former Yugoslavia, Switzerland and other East Europian countries.

➤ Low supercooled clouds and fogs are dispersed to clear the airports in winters for smooth landing and take off of air crafts. In all the cases enormous heat energy employed to induce precipitation, to prevent hailstorms, and to disperse and clear clouds and fogs is released and it causes additional heating of the lower layer of the atmosphere and thus changes the natural meteorological processes.

➤ Modern technologies have enabled the man to construct huge dams and reservoirs for the purpose of irrigation and generation of hydroelectricity which is immensely required by the industrial sector to augment the production processes and by the domestic sector to increase the comfort of human beings. Such activities create several enviornmental problems of greater dimension. (a) Construction of huge dams and reservoirs upset the equilibrium of rocks below the ground surface where the area is already tectonically weak and thus is triggered off massive seismic events because the load of water of lakes and reservoirs constructed behind the dams on major rivers increases hydrostatic pressure which causes disturbances in the underlying rocks. The earthquakes of Denever since 1962 (Denever, Calorado, U.S.A.), Lake Kariba earthquake (on Zambezi river in Zambia, Africa), Koyana earthquake of December 11, 1967 (Satara, Maharashtra, India) etc. are a few exampels of man-induced earthquakes. There is much hue and cry agaisnt the construction of gigantic Tehri Dam on the Ganga river at Tehri in the Uttarakhand Himalaya (India). (b) Large reservoirs submerge vast areas of natural forests and thus degrade the environment in the source catchment area of the concerned river.

➤ Modern techniques of increased agricultural production demand increased application of chemical fertilizers (to increase the productivity of the soils) and pesticides, insecticides, and herbicides (to remove plant diseases and destroy unwanted weeds). These chemical elements pollute the soils by changing their physical and chemical properties on the one hand, and the surface waters of ponds, lakes and streams and groundwater because of gradual accumulation of toxic chemical elements on the other hand.

➤ The manufacturing and use of several luxury items such as refrigerators, airconditioners, spraycan dispensers, hair driers and the operation of fire extinguishers etc. release substantial quantity of chlorofluorocarbons and halons into the atmosphere which deplete the life saving ozone layer of the stratosphere. Depletion of ozone means disturbance in the global radiation and heat balance of the earth and its atmosphere because more and more ultraviolet solar rays would reach the earth's surface and thus the temperature would be increased. Increase in the earth's temperature due to depletion of ozone would cause adverse effects on human bodies (skin cancer) and on plant and animal lives.

➤ Increased burning of fossil fuels in the thermal power stations and in the factories to generate more and more energy to run the machiens releases huge quantity of carbon dioxide in the atmosphere. Thus everincreasing concentration of carbon dioxide in the atmospehre intensifies **greenhouse effects** and thus raises earth's temperature and disturbs radiation and heat balance.

➤ Leakage of toxic gases from chemical plants not only pollute the air but also causes deaths of human beings, plants and animals immediately (within minutes) and causes impairment of human bodies for several years even for few generations. The Bhopal gas tragedy of December 3-4, 1984 (Bhopal, Madhya Pradesh, India) is the fittest example of lethal effects of the failures of modern technology. The leakage of 30 tonnes of toxic poisonous MIC gas (Methyl Iso-Cyanide) from a storage tank of pesticide and insecticide manufcturing Union Carbide Factory of Bhopal (India) in 1984 (December 3-4, 1984) is the worst disaster of chemical industry as the fast spreading poisonous gas killed 3598 people (official figure being 2500) and thousands of animals and innumerable microorganisms. Nuclear disaster of nuclear plant at Chernobyl, Ukraine, in 1986 is another example of disastrous impact of modern technologies on the very existence of human society.

➤ Numerous toxic industrial wastes also cause serious enviornmental problems. About 2000 new chemicals are released to the environments each year from the industrial establishments. According to experts some of these toxic chemicals mostly through food are trasported across the placentas and reach the developing foetus of woman and cause abortions and premature labour. Hydrogen sulphide and sulphur dioxide gases released from the rayon manufacturing plants cause severe environmental pollution as these cause respiratory problems in human bodies and induce acid rains.

The adverse effects of modern technologies are so immense that it may not be possible to enlist them individually. The most dangerous outcome of the modern technologies is the production of a host of toxic chemicals, synthetic materials and biologically non-degradable materials. The problem of disposal of some new products of modern technologies such as plastics has become headache even for the industrially developed and technologically advanced countries. The most dangerous aspect of modern technologies is the problem of disposal of nuclear waste materials coming out of the nulcear reactor plants. Above all, the manufacturing of nuclar bombs is graveyard dug out by man for himself. In case of nuclear war the whole of the globe and entire biological commuity including human beings will be destroyed due to nuclear holocaust and nuclear winter within no time.

CONCLUSIONS

It is apparent from the aforesaid discussion that the processes and causes (as enlisted above) for the environmental degradation present a gloomy picture for future life and all the developmental works are anti-nature because these degrade the environment. It may be born in mind that the pace of developmental work has to be maintained if we want to maintain the present human society but the development should not be at the cost of the environment becuase it is the natural environment which ensures our existence.

"There are clearly a number of divergent (and at times conflicting) theories of what are the basic causal factors underlying the recent envirnomanal problem of pollution and resource depletion. It seems fair to conclude that individual aspects of recent environmental changes can be associated with different factors. The search for one overriding root cause would apear to be largely academic because it seems clear that each of the major causes could be operating simultaneously and that their balance will vary from place to place and through time" (C.C. Park, 1980, p. 28).

In fact, the interaction between the envirnment and society depends largely on the social and political systems within which arise the environmental and ecological problems. The capitalistic and socialistic systems' perception and reactions to the environment are quite different. The capitalistic system of government of the western world is full of contradictions regarding the exploitation of natural resources, rate of development, use of modern technologies and conservation of environmental resources and maintenance of ecological balance.

Continuous but exceedingly increasing rate of rapacious exploitation of natural resources and uncontrolled rapid rate of developments by the developed western world monopolistic groups and selfish international companies are responsible for alarming situation of grave problems of enviornmental degradation, environmental crises and ecological imbalance not confined to the limits of their own countries and regions but to whole globe. In fact, the inherent ideology of capitalism is to increase production with minimum production cost but for maximum profit leading to accumulation and hoarding of wealth on the one hand, and to shift the responsibility of environmental degradation on the shoulders of developing and underdeveloped countries on the other hand. Conversely, they are raising the siren of 'ecological catastrophe', 'society of zero growth', 'equilibrium society', etc. so that the consumption of natural resources may be frozen and economic growth may be suspended. In fact, the pessimistic ideology of the western capitalistic world is painting a gloomy picture of environmental degradation and ecological imbalance before the developing countries so much so to discourage the use of modern technology and launching of developmental progammes so that they remain their perennial markets where the factory produce from the western world may continue to be dumped.

On the other hand, the socialistic system of government lays more emphasis on the social importance of natural resources and enviornmental and ecological problems and on the urgent need to tackle these problems. The inherent socialist ideology of public ownership of natural resources is explicit expression of effective nature conservance. In other words, the deep involvement of society in production and consumption processes injects a sense of belonging to natural wealth and therefore the public becomes conscious about the uses and misuses of natural rescours and environmental problems arising therefrom.

To my mind, as stated earlier, the root cause of environemental degradation and ecological imbalance is population growth. Various causes assigned to environmental degradation such as rapid rate of deforestation because of industrial and urban expansion and extension of agricultural land; agricultural development and everincreasing use of chemical fertilizers, pesticides, insecticides and herbicides to increase agricultural producton, industrial development; urban expansion; modern technologies; scientific advancement; economic poverty and lack of environmental perception; economic affluence and materialistic outlook; excessive exploitation of natural resources and several types of developmental projects and programmes are, in fact, related to population growth in one way or the other. Thus the utmost important step to be taken to tackle the problems of enviornmental degradation and ecological imbalance is to check the population growth. The other measures to tackle the environmental problems include the following :

- development of pollution free and eco-friendly technologies,
- reduction in the exploitation of natural resources, i.e. rational exploitation,
- large-scale efforts to replenish the depleted forests through afforestation and reforestation schemes,
- to limit the use of chemical fertilizers, pesticides and insecticides and to increase the use of natural fertilizers,
- to treat the degraded land caused by rill and gully erosion,
- to limit the production of those items, such as refrigerators, air conditioners etc. and cosmetic goods, which release ozone depleting gases like chlorofluorocarbons, halones etc.,
- to limit the use of hydrocarbons to reduce the release of greenhouse gases like CO_2,
- to stop the production of nuclear weapons,
- to educate the people about the environment and environmental problems etc.

21

ENVIRONMENTAL POLLUTION

21.1 DEFINITIONS OF POLLUTION

The nature and meaning of environmental degradation and difference between environmental degradation and pollution have been discussed at length in chapter 20 of this book (see sections 20.1 and 20.2). In order to avoid repetition and to limit the format of this book these topics, as just referred, are not discussed here. However, it may be restated that environmental pollution means lowering of environmental quality at local scale caused exclusively by human activities whereas environmental degradation means lowering of environmental quality at local, regional and global levels by both natural processes and human activities. Both, environmental degradation and pollution, are considered in terms of man. Since the realization of environmental pollution has now become of global concern and there is growing awareness about pollution as **'vicious circle'** situation, a comprehensive study of pollution involving definitions and perception of pollution, types of pollution, sources of pollution, causes and processes of pollution, environmental and ecological effects of pollution, monitoring of pollution and pollution abatment programmes is not only desirable for environmental geographers and environmental scientists but is also necessary so that future strategies for resource utilization and comprehensive environmental management programmes may be formulated and implemented.

Since pollution is viewed from different angles as an environmental problem by the geographers in general and environmental geographers and natural scientists in particular; as a social problem by the sociologists; as an economic problem by the economists; as an ecological problem by the ecologists etc. and thus it may be defined in a number of ways. It is commonly agreed that pollution is, without doubt, the outcome of urban-industrial and technological revolution and rapacious and speedy exploitation of natural resources, increased rate of exchange of matter and energy and ever-increasing industrial wastes, urban effluents and consumer goods. A few definitions of pollution are given below :

1. According to the report of the Restoring the Quality of our Environment, President's Science Advisory Committee, Washington, USA, pollution may be defined as *"unfavourable alteration of our surroundings wholly or largely as a by-product of man's actions through direct or indirect effects of*

changes in energy patterns, radiation levels, chemical and physical constitution and the abundance of organisms."

2. According to D.M. Dixon (1972) *pollution* includes *"all those activities concious or unconscious of human beings and their domestic cattle and the result thereof which detract in any way...in the long-term or short-term, from enjoyment of his environment and his ability to derive full benefit therefrom".*

3. Pollution is viewed as *"the release of substances and energy as waste products of human activities which result in changes, usually harmful within the natural environment".*

Natural Environmental Research
Council (NERC) 1976

4. *"Residuals, or wastes, are generated in all stages of production and consumption of goods or services. Residuals become pollutants or an environmental problem of some kind and in some degree when they have harmful effects in the atmosphere, the oceans or the terrestrial environment. Harmful effects are effects that are harmful to man, or to animals, plants or inanimate objects or conditions that are important to man. Their importance to man may be biological, economic, religious, moral, aesthetic or intellectual."*

Massachusetts Institute of Technology
(MIT), 1970.

5. Pollution is defined as *"the presence at large of substances, or energy patterns which have been involuntarily produced, have outlived their purpose, have escaped by accident, or have unforseen effects, in quantities which harm his (man's) health or do offend him".*

Lord Kenett

6. R.F. Dasmann (1975) has defined pollution as *"the accumulation of substances, or forms of energy, in the environment in the quantities, or at rates of flow, which exceed the capacity of ecosystems to either neutralize or desperse them to harmless levels. Pollutants are not necessarily harmful in themselves."*

7. Savindra Singh (1991) has defined pollution in a very simple manner. This definition, as given below, may be applied to all types of pollution ranging from physical to economic, political, social and religious pollution :

'Disequilibrium condition from equilibrium condition in any system is called pollution.'

Savindra Singh

It is apparent from the above definitions of pollution that there are three criteria, as mentioned by N. Lee and C. Wood (1972) for defining pollution viz. (i) the waste materials resulting from human activities and disposal of wastes, (ii) damages caused by disposed wastes whether directly or indirectly, and (iii) the circumstances where the effect of damage is met by third parties.

21.2 POLLUTANTS

A pollutant is defined as any form of energy, or matter or action that causes disequilibrium state from equilibrium state in any existing natural ecosystem. Pollutants are divided on different bases into various types as follows :

(1) On the basis of **source of genesis,** pollutants are divided into two main types :

(i) natural pollutants, and

(ii) man-made pollutants.

Natural pollutants are manageable because of the laws of cybernetics or homeostatic mechanism. But unfortunately man is not making any permanent arrangement for pollutants made by himself'.

(2) Pollutants are divided on the basis of **visibility** into the following two types :

(i) visible pollutants, and

(ii) invisible pollutants.

Visible pollutants include smoke, gases, dusts coming out of 'human volcanoes' (chimneys), waste water or sewage water coming out from factories and urban areas, heaps of garbages, animal and human wastes etc. whereas invisible pollutants include several types of bacteria, toxic chemicals mixed with water and soils etc.

(3) Pollutants may be classified on the basis of their **state** as follows :

(i) **solid particulate**

pollutants (aerosols, industrial wastes such as lead, mercury, tailings, asbestos etc.)

(ii) **gaseous pollutants**

(chlorofluorocarbons, carbon dioxide, sulphur dioxide, nitrogen oxides, carbon monoxides, methan etc.)

(iii) **liquid pollutants**

(oil slicks, dissolved solids, ammonia, urea, nitrate, chloride, fluoride, carbonates, pesticides and insecticidies etc.—all in dissolved form, oil and greases etc.)

(4) Pollutants are also divided on the basis of their **nature** into the following 3 types :

(i) physical pollutants,

(ii) cultural pollutants, and

(iii) biological pollutants.

Physical pollutants include all natural as well as man-made pollutants in gaseous, solid and liquid state as referred to above. Cultural pollutants include over-population or say explosive population, poverty, crime, richness, cultural backwardness etc. whereas biological pollutants include eutrophication, locust swarms etc.

(5) Pollutants may also be divided on the basis of **areas polluted** by specific pollutant and group of pollutants into 3 types :

(i) **air pollutants**

(e.g. particulate matter, gases, smokes, soots etc.)

(ii) **water pollutants**

(e.g. dissolved and suspended solids, different types of ions, pesticides and insecticides residues, toxic metals such as lead, mercury and cadmium, radioactive wastes etc.)

(iii) **land pollutants**

(e.g. human and animal excreta, garbage, pesticides, insecticides and chemical fertilizers, machines and tools, radio active substances etc.

The Massachusetts Institute of Technology (MIT, 1970) has identified more than a million kinds of products produced by man which are both waste and useful products that eventually turn to be wastes after their uses. MIT has also specified a series of key pollutants which create critical environmental problems.

Table 21.1 : List of key pollutants specified by the Massachussetts Institute of Technology (MIT, USA, 1970)

1. carbon dioxide
2. particulate matter
3. sulphur dioxide
4. oxides of nitrogen
5. toxic heavy metals
   (lead, mercury, arscenic,
   cadmium, nickel, manganese, copper, zinc)
6. oil
7. chlorinated hydrocarbons
   (especially DDT and polychlorinated
   biphenys-PCB)
8. other hydrocarbons
9. radionuclides
10. heat
11. nutrients

The United States National Academy of Sciences-National Research Council (USNAS-NRC) has identified 8 broad types of pollutants which enter watercourses. These pollutants include heat from power plants, sediments from land erosion and radioactive substances. These pollutants are given in table. 21.2

Table 21.2 : Main types of pollutants which enter the water courses in the USA (USNAS-NRC)

1. Domestic sewage and other oxygen demanding wastes
2. Infectious agents
3. Plant nutrients
4. Organic chemicals which are highly toxic at very low concentrations (such as insecticides, pesticides, detergents, and petrochemicals)
5. Minerals and chemicals (including chemical residues, salts, acids, silts and sludges)
6. Sediments from land erosion
7. Radioactive substances
8. Heat from power and industrial plants

21.3 SOURCES OF POLLUTION

The pollutants, as described earlier, are produced by both natural and anthropogenic processes and therefore the sources of pollution on this basis are divided in two categories viz. **natural source** of pollution, and (ii) **anthropogenic** source of pollution. **Natural source** of pollution includes pollutants such as volcanic ashes and dusts from volcanic eruptions (volcanic dust layers in the atmosphere reduce air temperature); undesirable substances brought to the surface because of fracture and faults caused by seismic events; flood water in lowlying area causes diseases etc. Anthropogenic source of pollution is varied and is the main culprit of environmental pollution because the nature takes care of natural pollutants because of inbuilt mechanism of absorbing any change brought in the nature by natural processes.

Anthropogenic sources of pollution include (i) industrial source, (ii) urban source, (iii) agricultural source, (iv) population source etc. Most of the pollutants come from industrial and urban sectors. The industrial source contributes a host of pollutants such as gaseous pollutants (nitrogen oxides, sulphur dioxide, carbon monoxides, hydrocarbon as methane and numerous toxic gases), solid pollutants, dissolved and suspended solids, waste water having numerous chemical ingredients, heat etc. Urban sources of pollution contribute sewage water, solid waste, gaseous exhausts, liquid effluents, pollutants coming out of chimneys of factories located within the urban centres etc. Agricultural source of pollution includes the pollutants related to chemical fertilizers, pesticides and insecticides. Human population is the most important source of pollution because all forms of anthropogenic pollution are the creation of human activities. On an average the increase in the population of a nation has been positively correlated with pollution. The everincreasing population in the developing countries is posing as much problem of pollution as in the developed countries through industrial growth and urban expansion. Poverty and underdevelopment are yet other sources of pollution.

21.4 TYPES OF POLLUTION

The classification of environmental pollution is a difficult task because the pollutants and the media through which the pollutants are transported and diffused (such as air, water and land) are all interconnected and interrelated and thus all types of pollution, identified so far, are arbitrary in character. Inspite of the drawback of arbitrariness in he typology of pollutions they are classified in a number of ways on various grounds as elaborated below :

1. **On the basis of nature of pollution**
    - (1) **physical pollution**
        - (i) land pollution,
        - (ii) water pollution, and
        - (iii) air pollution
    - (2) **social pollution**
        - (i) economic pollution, (poverty)
        - (ii) religious pollution (communal riots and violence)
        - (iii) political pollution (wars)
        - (iv) ethnic pollution (ethnic riots)
        - (v) social pollution (crimes such as robbery, rape, dacoity, murders etc.)

2. **On the basis of medium of pollution**
    (1) land pollution
    (2) water pollution
    (3) air pollution
3. **On the basis of area and source of pollution**
    (1) urban pollution
    (2) rural pollution
    (3) industrial pollution
    (4) agricultural pollution
4. **On the basis of location of pollution**
    (1) point pollution
    (2) non-point pollution
        (i) rural non-point pollution
        (ii) urban non-point pollution

1. Point Pollution

Point pollution is always visible and hence can be easily identified. Discharge of effluents from a drain or pipe into a river channel is termed **point-source pollution** or simply a point pollution. In fact, point pollution means coming out of pollutants from a specific location such as outfall of sewer drains in a river or a creek, outfall of drains of industrial waste water, chimneys of factories etc. whereas nonpoint pollution means pollution of the area from unspecified location. Nonpoint pollution includes washing of fertilizers and pesticides from agricultural land into streams. Thus nonpoint pollution is seldom visible. For example, chemical fertilizers and pesticides and insecticides used in the agricultural fields are washed out during rains and thus are brought to the streams.

2. Non-point Pollution

Nonpoint pollution mostly occurs from agricultural practices. The chemicals used in the form of plant nutrients as fertilizers and in the form of pesticides and insecticides in the agricultural farms are brought to the tanks and ponds, lakes and streams in dissolved and solid forms. The main medium or agent of nonpoint pollution is surface runoff resulting from atmospheric rainfall. The rainwater transports pollutants in two directions viz. (i) lateral movement of pollutants through surface runoff, and (ii) downward movement of pollutants through infiltrating and percolating water. Thus nonpoint pollution involves both surface water and groundwater. Infact, nonpoint pollution is a slow poisoning of our physical environment mainly surface and subsurface waters and soils. The polluted water in turn adversely affects biological communities in general and human community in particular and soil pollution results in phenomenal decrease in fertility and productivity which causes drastic reduction in agricultural production and hence consequent substantial shortage of food supply may cause economic pollution through poverty, starvation and deaths.

Besides chemicals, eroded sediments and silts brought down by the surface runoff from the land to lakes, reservoirs and rivers are also significant pollutants and cause nonpoint pollution of lakes and rivers through increased proportion of suspended solids and sediment loads in the water and consequent sedimentation and siltation of lakes, reservoirs and river beds.

The rainwater after having numerous chemicals in dissolved forms (rainwater receives several chemicals from the agricultural farms which are treated with chemical fertilizers and pesticides and insecticides) infiltrates downward and hence these chemicals are also moved downward to pollute groundwater.

Non-point pollution is further divided into two types :

(i) rural or agricultural nonpoint pollution

(ii) urban nonpoint pollution

(i) **Rural nonpoint pollution :** The major source of nonpoint pollution in rural areas is agricultural activity. Since rural nonpoint pollution is basically related to agricultural activities, it is also called as **agricultural pollution.** Nature and amount of chemical fertilizers, pesticides and insecticides applied to the farms, types of soils, amount and intensity of annual rainfall, other climatic conditions, methods of ploughing and farm management techniques, nature and slope of ground surface, nature of crops etc. are the factors which determine the nature and magnitude of nonpoint pollution in rural areas.

(ii) **Urban nonpoint pollution :** Though the sources of urban nonpoint pollution are varied and uncertain yet these are divided into 3 categories viz. (a) pollutants coming from residential areas, the amount of which depends on the density of houses, (ii) pollutants coming from small-scale industries, and

(iii) pollutants coming from large-scale industries.

In the regions of extreme cold climate roads are covered with ice sheets during winter season and hence salts are used to melt the ice so that the roads can be kept open and traffic flow and road drainage can be properly maintained. The process (melting of ice) is called **de-icing**. Thus enormous quantity of salts used for melting the road ice is washed out to reach the nearby streams which are thus characterized by higher proportion of salt or say high salinity. "The total amount of de-icing chemicals used in the USA is probably close to 2 million tonnes per year and there is growing concern over possible effects on receiving streams."

Numerous small catchment studies to evaluate the impact of nonpoint pollution from agricultural areas in the USA on nutrient loadsings of the streams have shown positive relationship between land use types and concentration of chemicals in the rivers. The findings of the study of NES (National Eutrophication Survey, USA) regarding the measurement of relationships between stream nutrient loadings and watershed land use in 473 small basins to the east of the Mississippi river (selected from different areas having different land uses e.g. forest, mostly forest, mixed, mostly urban, mostly agricultural and agriculture) revealed a vast difference in the total mean concentration of phosphorous (0.15 mg per litre of water in the agriculture-dominated watersheds and 0.04 mg per litre of water in the forest-dominated basins) and nitrogen (4.17 mg and 0.85 mg per litre of water for agriculture-dominated and forest-dominated basins respectively) which is because of the use of fertilizers in the agricultural watersheds.

No significant attempts have been made so far to assess the nature and amount of nonpoint pollution in India though rapid rate of growth in the constructions of buildings and roads, phenomenal increase in soil erosion, substantial increase in the use of chemical fertilizers, pesticides and insecticides and industrial expansion and urban growth have definitely augmented the rate of nonpoint pollution.

21.5 AIR POLLUTION

1. MEANING AND DEFINITION

The atmosphere is a gaseous envelope which surrounds the earth from all sides and the air is a mechanical mixture of several gases, mainly, nitrogen (78.09%), oxygen (20.95%), argan (0.93%) and carbon dioxide (0.03%). Besides, other trace gases like neon, krypton, helium, hydrogen, xenon and ozone are also present. Air is very important for all types of life in the biosphere. Human life is not possible without air because man can live for a few days without water or for a few weeks without food but cannot survive even for a few minutes without air. It constitutes about 80 per cent of the total intake of all things by a person every day as a person breathes 22,000 times a day inhaling 35 gallons or 16 kilograms of air which he obtains from the oxygen rich atmosphere surrounding the earth.

It may be pointed out that air is never pure because some gases such as sulphur dioxide, hydrogen sulphide, carbon monoxide; emissions from volcanoes and swamps, windblown dusts, salt spray, pollens from plants etc. are continuously added to the air by the natural processes. Thus the air becomes polluted when its natural composition is disturbed either by natural or man-made sources or by both. A few definitions of air pollution are given below :

(1) *H. Perkins (1974) has defined air pollution as "the presence in the outdoor atmosphere of one or more contaminants such as dust, fumes, gas, mist, odour, smoke or vapour in quantities of characteristics and of duration such as to be injurious to human, plant or animal life and to property or which unreasonably interferes with the comfortable enjoyment of life and property."*

(2) *Air pollution is defined as limited to situation in which the outdoor ambient atmosphere contains materials in concentration, which are harmful to man and his surrounding environment.*

WHO

(3) *In a general sense air pollution may be defined as the disequilibrium condition of the air caused due to introduction of foreign elements from natural as well as anthropogenic sources to the air so that the air becomes injurious to biological communities in general and human community in particular.* Savindra Singh, 1991

Air pollution is generally accomplished through the pollutants of gases and solid and liquid particles of both organic and inorganic chemical classification important being carbon dioxide, fluorocarbons, nitrogen oxides, sulphur compounds, waste heat, water vapour, ammonia, hydrocarbons, methane, peroxyacetylnitrates, methyl bromide, krypton-85, aerosol etc. It is significant to note that air pollution through natural sources including volcanic dusts, windblown dusts, vapour from plant leaves, rotting materials in the natural environment, pollens from plant flowers etc. does not warrant much concern because "such pollutants can be considered to be accommodated within the global ecology" (J.E. Hobbs, 1980) because they (natural pollutants) are distributed all over the globe but man-made pollutants are injected and concentrated in certain localities of their sources mainly in highly industrialized and urbanized pockets of the world. In other words, the pollutants coming out of natural sources are generally absorbed by the natural environment and no pollutional problem arises but man-made pollutants being concentrated in certain parts of the atmosphere pollute the air.

The **nature, dimension** and **magnitude of air pollution** depend on a variety of factors such as residence time of pollutants in the atmosphere (duration of stay of pollutants in the atmosphere), sources of pollutants, nature of pollutants, amount of pollutants etc. "The residence time of pollutants in the atmosphere (also) vary considerably, depending upon the nature of the pollutant itself, upon the way emission has taken place, on meteorological factors (e.g. amount of moisture content in the air, air temperature, nature of air circulation, nature of air pressure, cloudiness etc.), and on sink mechanisms (absorption of pollutants such as nature of vegetation, water bodies etc.)" (H.E. Hobbs, 1980)

2. SOURCES AND TYPES OF AIR POLLUTION

Major sources of air pollution are divided into two broad categories :

(1) **natural sources**
   (e.g. volcanic eruptions, deflation of sands and dusts, forest fires etc.)

(2) **anthropogenic sources**
   (e.g. industries, urban centers, automobiles, aircrafts, agriculture, power plants etc.)

3. NATURE OF AIR POLLUTANTS

Like sources of air pollutants and pollution, air pollutants are also divided on the basis of sources into the following two broad categories :

(1) **natural pollutants**
   (a) from volcanic eruptions; dusts, ashes, smoke, carbon dioxide and other gases;
   (b) from extra-terrestrial bodies; cosmic dusts, dusts produced due to collision of asteroids, meteors, comets etc. with the earth;
   (c) from green plants : vapour through evapotranspiration, pollen from plant flowers, carbon dioxide from bacteria;
   (d) from fungi; fungal spores, viruses etc.;
   (e) from land surface; salt spray from seas and lakes, dusts and soil particles from ground surface.

(2) **anthropogenic pollutants**
   (a) gases from kitchen and domestic heating, industries, incineration of municipal and domestic garbages, automobiles, diesel locomotives of railways, aircrafts etc.;
   (b) particulate matter from industries, mines, and urban centers mostly from automobiles;
   (c) radioactive substances from nuclear plants, nuclear fuel releases, nuclear tests etc.;
   (d) heat from industries, domestic kitchens and room heating, thermal power plants etc.

Air pollutants are also divided on the basis of the nature of pollutants into the following two broad categories;

(1) **gaseous air pollutants**
   (a) Carbon dioxide (CO_2), carbon monoxide (CO) from combustion of fossil fuels, transportation sector, industrial processes and garbage disposal,
   (b) hydrocarbons (carbon and hydrogen containing compounds in oxygenated hydrocarbon) from incomplete combustion of fuels,
   (c) fluorocarbons from aerosol cans, and refrigeration systems,
   (d) sulphur compounds such as SO_2 and SO_3, H_2S (hydrogen sulphide) and H_2SO_4 (sulphuric acids) from the burning of sulphur containing fossil fuels,

(e) nitrogen oxides and other nitrogenous compounds such as NO_2 (nitrogen dioxide), N_2O (nitrous oxides), NO (nitric oxide) and NO_3 (nitrogen trioxide) from high flying aircrafts, combustion of fossil fuels and from chemical fertilizers,

(f) aldehydes from thermal decomposition of fats, oils, or glycerol, and

(g) chlorine from bleaching cotton cloths and flour and many other chemical processes.

(2) **particulate air pollutants**

(a) aerosols : are those fine particles which are around one micron to 10 microns in size, these are added to the atmosphere by industries, thermal power generation, automobiles, space heating, agricultural activities etc.,

(b) smokes, soots and fumes are smaller than aerosols in size and are added to the atmosphere through the incineration of municipal and domestic wastes, thermal power plants and almost all types of manufacturing processes, and

(d) dusts include those solid particles which are larger than aerosols in size, these are added to the air from all types of combustions and agriculture.

Particulate pollutants are also divided into the following two types :

(i) **visible or living particulate matter**

e.g. bacteria, pollen grains, fungal and other spores, all of which belong to the category of natural air pollutants.

(ii) **non-living particulate matter**

e.g. all of the pollutants whether gaseous or particulate from anthropogenic sources as referred to above.

4. TYPES OF AIR POLLUTION

Air pollution may be divided on two bases as follows :

(1) on the basis of types of pollutants, and

(2) on the basis of sources of air pollutants.

(1) On the basis of types of air pollutants, air pollution is divided into two major types :

(i) gaseous air pollution, and

(ii) particulate air pollution.

(2) On the basis of sources of air pollutants, air pollution is divided into the following types :

(a) automobiles air pollution,

(b) industrial in pollution,

(c) thermal air pollution,

(d) urban air pollution,

(e) rural air pollution, and

(f) nuclear air pollution.

The description of air pollution may be approached in a number of ways such as (i) on the basis of pollutants, (ii) on the basis of sources of pollution etc. Only one approach should be adopted because all the approaches are overlapping. The present author has opted for the topical description of air pollution based on major pollutants. It may be pointed out that the nature of air pollution is so complicated due to a host of pollutants that it becomes difficult to isolate the major pollutants.

Cabon Monoxide and Air Pollution

The major source of the production of carbon monoxide (CO) is incomplete burning of fossil fuels like coal and petroleum and wood charcoal. The automobiles using diesel and petroleum are the major source of carbon monoxide. Besides, carbon monoxides are also produced from oil refineries, metallurgical operations and numerous combustion engines. It is apparent that urban areas and industrial centres are the most significant contributors of carbon monoxide because they account for the largest number of automobiles and industries. According to an estimate about 6 billion tones of carbon monoxide are annually produced and emitted in the atmosphere at global level. Thus carbon monoxide constitutes about 50 per cent of the total air pollutants. The U.S.A. alone produces about 65 million tons of carbon monoxide per year. Other significant contributors of carbon monoxide are the countries located in the northern hemisphere such as Japan. Korea, former USSR (now CIS), U.K. France, Germany, Canada etc. India has also emerged as a major contributor of carbon monoxide to the atmosphere as Kolkata alone discharges 450 tones of carbon monoxide daily into the atmosphere. It may be mentioned that carbon monoxide is not toxic to plants but it causes respiratory problem and suffocation, when inhaled, in the human bodies. Inspite of the presence of oxygen in sufficient amount in a room with burning coal carbon monoxide causes suffocation and if the room is closed, it causes death.

Carbon Dioxide and Air Pollution

Carbon dioxide gas is one of the natural gaseous components of the atmosphere and in itself it is not harmful to human health rather it is a resource because plants manufacture their food through the process of photosynthesis by using carbon dioxide in the presence of sunlight and it is the food manufactured by green plants upon which depend all organisms including man. The content of CO_2 in the atmosphere is increasing at an alarming rate because of two major factors viz. (i) release of CO_2 due to burning of fossil fuels (coal and petroleum) at everincreasing rate, and (ii) gradual decrease in the consumption of CO_2 because of shrinking forest covers due to rapid rate of deforestation.

It is significant to note that pre-industrial level of atmospheric content of carbon dioxide (CO_2) was fixed at 0.028 to 0.029 per cent (280 to 290 p.p.m.) by volume but the atmospheric CO_2 has increased from the pre-industrial level to 368 ppm by 2000 A.D., thus registering an overall increase of 31 per cent from the pre-industrial level. It is believed that the rate of increase of atmospheric carbon dioxide through anthropogenic sources will be accelerated due to relentless march of developing countries towards industrial development and urbanization. Various models have been prepared to estimate the quantum of increase of CO_2 from man-made sources. According to S.H. Schneider (1975) a doubling of carbon dioxide (pre-industrial atmospheric partial pressure of CO_2 estimate as 293 p.p.m) to about 600 p.p.m. may increase atmospheric temperature by 1.5°C to 3.0°C. Hoffman and Wells (1987) have remarked that the atmospheric content of carbon dioxide has risen by 25 per cent since industrial revolution and is expected to double (100 per cent rise from the pre-industrial level) by the middle of the 21st century.

According to the IPCC report 2001 (Intergovernmental Panel on Climate Change) if no effective measures are adopted to stabilize the emission of CO_2 at 1992 level by worldover, its atmospheric concentration would increase to 405-460 ppm by 2050 A.D.; and 540-970 ppm by the end of 21st century.

Table 21. 3 : Estimated emissions of major pollutants from fuel sources in India

		Estimated Pollutant Emissions (in thousand tonnes)								
Fuels Sources	Quantity consumed per year (million tonnes)	Particulates	CO_2	SO_2	NO	Hydrocarbons	H_2S	NH_3	HCL	Total pollutants
Commercial										
1. Coal	67.6	2160	115	1350	270	1620	80	90	80	5750
2. Fuel (diesel, kerosine)	5.9	1	35	100	41	110	1	1	1	290
3. Petroleum (automobiles, aircrafts)	1.6	3.2	720	1.6	32	128	1.6	1.6	1.6	890

4. Natural Gas	0.8	0.3	-	0.2	3.6	1.8	0.3	0.2	0.2	7
5. Petroleum (refinery operations)	12.0	1.7	26	13	11	8	-	-	-	60
Non-Commercial										
6. Firewood	100	3140	163	1960	390	2350	120	120	180	8360
7. Dry cattle dung	55	720	38	450	90	540	25	25	25	1910
8. Vegetable waste product	32	960	57	600	120	720	36	36	36	2560
9. Refuse burning	200	1400	1400	1000	1000	1400	-	-	-	6200
Total	475	8386	2548	5475	1958	6878	260	260	260	26,030

Source : NEERI, Nagpur, 1965-66.

The higher concentration of carbon dioxide in the atmosphere increases the **greenhouse effect** (see section 13.9 (1), Chapter 13 of this book) of the atmosphere and thus increases the temperature of the earth's surface because carbon dioxide is more or less transparent to incoming shortwave solar radiation and thus allows the solar radiation to pass through the atmosphere and reach the earth's surface but stops the outgoing longwave terrestrial radiation from escaping to the space. In other words, atmospheric carbon dioxide together with other greenhouse gases trap the outgoing heat radiation waves of the earth and thus warms up the air which results in gradual increase in the temperature of the earth's surface and the lower atmosphere.

The increasing content of atmospheric carbon dioxide from anthropogenic sources is expected to have far reaching effects on global climate through gradual rise in temperature as given below :

- There may be substantial decrease in precipitation and soil moisture content in the most developed agricultural regions of the world.
- There would be gradual increase in oceanic salinity which would decrease biological productivity of marine ecosystem which would change the albedo of the ocean surface.
- There would be melting of continental and mountain glaciers and consequent rise in sea level and resultant flooding of coastal lowlands.

Chlorofluorocarbons and Ozone Depletion

The chlorofluorocarbons, popularly known as CFCs, belonging to the category of chemicals synthesised by man for use in several kinds of industries including refrigeration, are relatively simple compounds of the elements **chlorine, fluorine,** and **carbon** and are initially stable compounds which do not have any toxic effect on life processes in the biosphere at the ground level. These synthetic chemicals are widely used as propellants in spray can dispensers, as fluids in airconditioners and refrigerators, as blowing agents in insulation foams (popularly known as styrofoam) and as industrial solvents. It is estimated that about 25 per cent of the total world production of chlorofluorocarbons is used to propel 'personal care products' such as deodorants, hair sprays, shaving creams and numerous other cosmetic products. The most important of the chlorofluorocarbons-hydrocarbons-are the trichlorofluoromethane (trade name freon 11) and dichlorofluoromethane (trade name freon 12).

The emissions of chlorofluorocarbons (CFCs) in aerosol and non-aerosol forms from aerosol spray cans, airconditioners, refrigerators, foam plastics, fire extinguishers (halons), cosmetic goods etc. into the troposhere and their transport to the stratosphere increase the concentration of chlorofluorocarbons because these keep on accumulating in the stratosphere as they do not degrade for a long period of time. The chlorofluorocarbons (CFCs), after being broken down by the ultra-violet solar radiation, destroy the strong ozone which acts as a protective cover for all biotic communities of the biosphere because ozone layer absorbs ultraviolet solar radiation and this protects the earth from becoming too hot.

It may be pointed out that the air is being increasingly polluted due to release of CFCs in the atmosphere. The atmospheric concentration of CFCs is increasing rapidly at the rate of 13 to 28 per cent (of freon 11) per annum. Thus the depletion of ozone (see chapter 13) due to increased concentration of chlorofluorocarbons (CFCs) is one of the most dangerous forms of air pollution.

Thus the ozone depletion caused by increased concentration of chlorofluorocarbon would adversely affect the global climate, biotic communities and human beings. It is believed that the depletion of ozone layer would result in 5 to 20 per cent more ultra-violet radiation reaching the populated areas of the world within coming 40 years. The substantial increase in the surface temperature of the earth would cause climatic changes at regional and global levels. The overall warming of the environment would cause melting of continental glaciers and ice caps such as those of Greenland and Antarctica. This would in turn cause rise in sea level and consequent submergence of coastal areas of lowlying countries.

The increased surface temperature and exposure of human bodies to increased ultra-violet solar radiation would cause skin cancer mainly among the white populations. According to an estimate 12 per cent decrease in ozone would cause skin cancer to 1,20,000 people per year in the USA alone. Secondly, increased exposure of human bodies to ultra-violet solar radiation would decrease immunity of human body against infectious diseases. Thirdly, increased ultra-violet radiation and consequent increased photochemical processes would cause poisonous smogs. Fourthly, human beings will face food shortage because of very severe adverse effects of increased ultra-violet solar radiation on agricultural crops, vegetation communities and fishes in the freshwater and marine aquatic ecosystems. (See chapter 13 for detailed discussion on effects of ozone depletion).

Methane and Air Pollution

The major sources of the production of methane (CH_4), which belongs to the category of greenhouse gases, are biologial processes such as enteric fermentation in cattle, sheep, and other animals, anaerobic situation in wetlands and rice fields and anthropogenic activities, such as burning of biomass and fossil fuels (coal, petroleum and natural gas). Concentration of methane gas in the stratosphere increases water vapour there and thus increased water vapour together with other factors intensifies greenhouse effect of the atmosphere which causes rise in the temperature of the earth's surface. According to an estimate about 400 to 765× 10^{12} grams of methane gas are added to the atmosphere every year.

Sulphur Dioxide and Air Pollution

Sulphur dioxide gas (SO_2) is produced by both natural and man-made sources. After carbon monoxide (CO), sulphur dioxide is the second most important contributor of air pollutants as it accounts for about 29 per cent of the total weight of all air pollutants. It may be pointed out that sulphur is essential element for both plants and animals only in trace amount but when the concentration of sulphur increases in the atmosphere, it becomes injurious to both plants and animals because increased concentration of sulphur increases the acidity of water and lowers the pH of water significantly. The major man-made sources of sulphur dioxide are thermal power plants (where huge amount of coal is burnt to generate power), crude oil refineries and automobiles which together account for 50 per cent of total SO_2 pollution from man-originated sources.

Sulphur dioxide (SO_2) through the photochemical reactions with atmospheric oxygen (O_2) and with water films on suspended particulates produces sulphuric acids (H_2SO_4) which is highly corrosive and leading culprit to human health and wealth. Sulphuric acids coming down with rainfall cause **acid rain** having very low pH value ranging between 5 and 2.5. Acid rain is very dangerous hazard as it causes irreparable damage to agricultural crops, forests, aquatic life and human bodies. It corrodes buildings, pollutes drinking water storage sources, and degrades soil biological processes. The sulphur cotnent present in coal and petroleum gets converted into sulphur dioxide (SO_2) on burning. This sulphur dioxide after combining with smoke over urban and industrial areas forms poisonous smog which causes respiratory diseases in human body and some times causes deaths.

Oxides of Nitrogen and Air Pollution

A few oxides of nitrogen such as nitric oxide (NO), nitrogen oxide (N_2O), nitrogen dioxide (NO_2) etc. are important air pollutants. Nitrogen oxides are formed through natural processes as well as through man-induced processes. The main sources of man-originated nitrogen oxides are thermal power stations, factories, automobiles and aircrafts. In other words, nitrogen oxides are released to the atmosphere through the burning of coal and petroleum. According to an estimate each ton of coal after burning produces between 5 to 10 kilograms of nitrogen oxide whereas one ton of diesel and petroleum consumed by transport vehicles (such as motor cars, trucks and two-wheelers) releases 25 to 30 kilogrms of nitrogen dioxide. High concentration of nitric oxide causes several diseases in human bodies such as gum inflamation, internal bleeding, oxygen deficiency, pneumonia, lung cancer etc. Nitrogen oxides released from the exhausts of large fleets of supersonic zet aircrafts (travelling at more than double the speed of sound and at a height more than 15,000 m, where ozone has its maximum concentration) are expected to reduce the concentration of ozone by 30 per cent. The studies have shown that even 5 per cent reduction in ozone in the atmosphere can cause between 20,000 to 60,000 additional cases of skin cancer in the USA alone (A.N. Strahler and A.H. Strahler, 1977).

Thermal Air Pollution

Heat energy released from industrial processes, space heating and cooling and power generation stations into the atmosphere is expected to upset the balance between solar energy input and absorption of solar energy at the earth's surface which may lead to some changes in general atmospheric conditions. According to W.W. Kelogg (1977) total world energy production through man-made sources in 1977 was about 10^4 GW (G = giga, one giga = 1 billion, W = watt) where as the absorbed solar energy at the earth's surface was about 8×10^7 GW. According to S.R. Hanna and F.A. Gifford heat emissions from a 4×10^4 MW (M = mega, which means one million = 1,000,000) nuclear power plant may cause and accelerate the formation of convective clouds and precipitation therefrom over the source region and may introduce slight ground fog within 100 km of cooling towers.

Particulate Matter and Air Pollution

The particulate matter includes smoke and soot, aerosols and dusts and mists. Aerosols are solid, liquid or solid-liquid particles ranging from 0.005 to 500 μm in diameter (Ormrod, 1984) but usually aerosols are considered to include the particles upto one micron in diameter. Particles being smaller in diameter than aerosols are called smoke and soot whereas particles larger than aerosols are called dusts when they are solid and mists when they are liquid. Several solid particulates are emitted from the industrial, urban and agricultural sectors, the fallout of which causes various types of health hazards to living beings on this planet earth.

Solid particulates such as dusts are divided into two categories based on the sources of their production e.g. (i) **metallic dust particulates** coming out of industrial, mining and metallurgical operations include dusts particles of aluminium, lead, copper, iron, zinc etc., and (ii) **non-metallic dust particulates** including particles or dusts of cement, glass, ceramics, asbestos etc. are produced from industrial operations. Lead particles are generally produced from petrol because lead is added to petrol as an antiknock agent. These particulate matters emitted in the air from man-made sources cause damages to biological communities in a variety of ways (to be discussed in the next subsection on effects of air pollution) and also cause more changes in weather conditions. Dust particles scatter solar radiation and thus affect radiation balance.

Domestic Air Pollution

Domestic air pollution includes pollution of air due to pollutants emitted from the houses and offices in both rural and urban areas. The major domestic pollutants are smokes from cigarettes, biri, cigars and other tabocco smokes, burning of coal, firewood, cow-dung cakes, kerosine oil and liquified gases. Thus there are three major sources of domestic air pollution e.g. (i) several forms of tobacoo smokes, (ii) kitchen smokes, and (iii) coal. The most widespread and serious domestic air pollutant is kitchen smoke mostly in the rural areas and slums of the urban areas in the developing countries. Most of the populations of rural India burn wood, twigs, leaf litters, cowdung cakes, coal and kerosine oil in the kitchens to cook food. The kitchens are generally located in unventilated rooms. These devices release enromous volume of soot and smokes which pollute the air in limited area particularly in and around that village concerned or a particular locality of the city. The 'chulhas' (ovens) in the rural areas are unscientifically designed and hence most of the smokes spread in the kitchen room, nearby rooms and some escape in the air through thatched roofs. Similarly, a sizeable portion of heat goes out unused. Recently, some fuel efficient 'chulhas' have been designed. The common pollutant gases emitted from domestic burning of coal, kerosine oil, firewood, cowdung cakes etc. are carbon monoxide (CO), carbon dioxide (CO_2), sulphur dioxide (SO_2) etc. Incomplete combustion of wood, coal, pady skins etc. releases carbon monoxide which reaches 50 p.p.m. or even more in unventilated kitchen room. Such polluted air causes eye diseases and suffocation. Several cases of deaths are reported from rural India during winter months due to suffocation caused by carbon monoxide and sulphur dioxide.

About 100 million tonnes of firewood are annually consumed in India for various purposes which produce 31,40,000 tonnes of particulate matter, 1,63,000 tonnes of carbon monoxie, 19,60,000 tonnes of sulphur dioxide, 3,90,000 tonnes of nitric oxides, 23,50,000 tonnes of hydrocarbons and total pollutants emitted from the burning of firewood amount to 83;60,000 tonnes per annum. The burnig of 55 million tonnes of cowdung cakes per year in India releases 7,20,000 tonnes of particulate matter, 38,000 tonnes of carbon monoxide, 4,50,000 tonnes of sulphur dioxide, 90,000 tonnes of nitric oxides, 5,40,000 tonnes of hydrocarbons per year whereas total pollutants from cowdung burning amount to 19,10,000 tonnes per annum.

5. ADVERSE EFFECTS OF AIR POLLUTION

The effects of air pollution on environment and human society may be grouped into the following 3 categories :

(1) effects on weather and climate,

(2) effects on human health, and

(3) effects on biotic community.

(1) Effects on Weather and Climate

Different types of air pollution caused by gaseous and particulate pollutants modify weather and climate at local, regional and global levels. A few of the climatological effects of air pollution are given below :

(i) Depletion of ozone caused by chlorofluorocarbons (CFCs) emitted from airconditioners, refrigerators, foam plastics, hair driers, spray can dispensers, fire extinguishers and many cosmetic goods and nitrogen oxides released by large fleets of supersonic jets travelling at more than double the speed of sound and at a height more than 15,000 m may change the radiation balance at global level. A detailed description of effects of ozone depletion has already been presented in chapter 13. The overall effect of ozone pollution (depletion is also a form of pollution) would be increase in the ultra-violet solar radiation reaching the earth's surface and therefore rise in the air temperature. Substantial increase in the surface temperature of the earth would cause global warming of the environment which would cause climatic changes at regional and global levels. Increased temperature would cause melting of continental glaciers and ice caps such as those of Antarctica and Greenland. This would in turn cause rise in sea level and consequent submergence of coastal lands of lowlying countries.

(ii) Increased concentration of carbon dioxide and other greenhouse gases in the atmosphere would intensify greenhouse effect of the atmosphere and thus the temperature of the earth's surface would increase which would cause climatic changes and would effect melting of continental glaciers and ice caps resulting into submergence of low coastal areas.

(iii) **Smog** : Smoky fog over the cities and industrial areas is generally called as smog or **urban smog.** Smog is generally formed when fog is mixed with smoke. When smog is mixed with air pollutants such as sulphur dioxide (SO_2), oxides of nitrogen (NOx) and ozone (O_3), it becomes poisonous and deadly health hazard to human beings. Sulphur dioxide is the main culprit in the formation of smog. It readily combines with atmospheric oxygen (O_2) and reacts with water films on suspended particulate matter (SPM) to produce sulphuric acid (H_2SO_4). This sulphuric acid after combining with smog makes it poisonous. Nitrous oxide (N_2O) forms nitric acid (HNO_3) which also makes smog poisonous. Ozone after reacting with hydrocarbon compounds forms some toxic compounds such as ethylene which is a common pollutant in urban smog. It may be pointed out that these air pollutants (sulphur dioxide, nitrogen oxides, ozone etc.) are trapped in a shallow layer over the cities caused by inversion of temperature (warmer air over cooler air) and thus are mixed with fog over the cities and industrial areas. The resultant fog having poisonous air pollutants is called urban smog and is highly undesirable weather phenomenon for society.

The incidents of deadly urban smogs of December 1930 in Meuse Valley of Belgium, of October 26, 1948 at Donora in Pennsylvania (USA), and of 1952 in London tell the ordeal of air pollution causing poisonous smogs. The poisonous smog of December 1930 of Meuse Valley of Belgium was caused due to trapping of huge volume of sulphur dioxide emitted from coke ovens, steel mills, blast furnaces, zinc smelters and sulphuric acid plants into a stagnant cold air layer, the result of inversion of temperature. This poisonous fog caused respiratory trouble in human beings, consequently 600 people fell ill and 63 people died. The five-day health disaster of Donora, Pennsylvania (USA) was preceded by the formation of thick fog due to strong inversion of temperature of October 26, 1948. The next day fog thickened and combined with sulphide fumes and soot spewed from mills and became a poisonous urban smog which claimed 20 human lives and 43 per cent of the total population of Donora became ill. A thick polluted fog, urban smog, was formed in December 1952 over London which claimed 4000 human lives mostly through respiratory diseases.

(iv) **Acid rains :** The fallout of acids with rains is called acid rain. In other words, 'rain made artificially acid by pollutants, particularly oxides of sulphur and nitrogen (natural rainwater is slightly acidic due to the effects of carbon dioxide dissolved in the water)' is called acid rain (D.B. Botkin and E.A. Keller, 1982). Acid rain simply means fall-out of acids caused by sulphur dioxide and nitrogen oxides with rainfall and thus increase in the amount of acidity of rainwater. As pointed out above rainwater is not pure because atmospheric carbon dioxide is dissolved in the rainwater which thus becomes moderately acidic, the pH being generally 5. The water with pH value of 7.0 is called neutral water whereas the pH value below it makes the water acidic and above the neutral point makes the water alkaline. The water becomes more injurious when the pH falls below 4.0.

Sulphur dioxide (SO_2) emitted from man-made sources (combustion of fossil fuels in factories, automobiles etc.) in larger quantities into the atmosphere combines with water to form sulphate and sulphuric acids (H_2SO_4). These acids fall on the earth's surface with rainfall and thus the fall of highly acidic water from above is called acid rain. The pH of rainwater in some localities of the USA mainly in West Virginia has gone down to 1.5, pH of rainwater in Europe is as low as 2.4 whereas the normal range of pH of neutral water must be 7.0.

The main sources of acid rains are oxides of sulphur and nitrogen which are emitted from industrial establishments and different types of vehicles. These pollutants are spread in the atmosphere by wind and form acids (sulphuric acids) after reacting with water in the atmosphere. It may be pointed out that acid rains are not confined to the source areas of the emissions of oxides of sulphur and nitrogen rather they cover much larger areas far away from the source of pollutants that cause acid rains because these pollutants being in gaseous phase are carried away and spread over larger areas through winds and clouds. For example, oxides of sulphur and nitrogen spread from several mills in Germany and U.K. have caused widespread acid rains in Scandinavian countries (Norway, Sweden) with the result most of the lakes in Scandinavian countries have lost their biological communities and are now biologically termed as 'dead lakes'.

Acid rains are very often called as **'lake killers'** in Anglo-American and west European countries because these rains have been identified as main factors of the 'deaths of lakes' which mean destruction and death of all aquatic lives including plants and animals in lakes, ponds and rivers. Out of 2,50,000 lakes of the state of Ontario (Canada), 50,000 have been adversely affected by phenomenal increase in the acidity of water and significant lowering of pH due to acid rains. Out of these lakes 140 have been declared as **'dead lakes'**.

Acid rains also affect human community adversely, though the mode of human diseases and death due to acid rains has not been properly understood as yet. According to American doctor Hamilton about 7,500 to 12,000 persons die of acidic sulphates coming out of the combustion of fossil fuels all over the globe every year.

The productivity of soils is also significantly lowered because of acid rains as increased acidity destroys mineral elements and other nutrients of the soils. Forests of Canada, the USA, Germany and many countries of middle Europe have been largely damaged due to acid rains. Acid rains also damage several monuments and buildings of historical importance due to corrosion. A siren of possible damage of world famous marble monument of Tajmahal at Agra, India, due to emissions of sulphur dioxide from the oil refinery at Mathura has been raised time and again. Several valuable sculptures and antiques of precious marble and other valuable stones are now being kept in the museums inorder to save them from the danger of acid rains in many of the western countries.

As pointed out earlier, acid rain is not a local problem or a problem of a particular country, rather it is an international problem because air pollutants emitted from a particular country are carried in the atmosphere by the winds and are spread over other countries. Thus the problem of acid rains should be tackled at international level. The acute problem of acid rains in the states of Quebec and Ontario of Canada is not only because of industrialization of these states rather it is more because of industrial growth and urban expansion in the Lake Region, Pittsburgh region and New England region of the USA.

The problem of acid rains in India is no longer alarming atleast at present time as the studies conducted by BARC (Bhabha Atmoc Research Centre, India) and WMO (World Meteorological Organization) have revealed no significant level of acidity in the rainwater over most of Indian cities.

(2) Effects on Human Health

➤ Carbon monoxide is major pollutant for human community because it combines with haemoglobine molecules of human blood much faster than oxygen (about 200 times faster than oxygen does) and thus causes suffocation inspite of the presence of sufficient amount of oxygen in the air.

➤ Depletion of ozone due to chlorofluorocarbons (CFCs) is expected to cause skin cancer mainly among white people because of increased exposure of human bodies to more ultra-violet solar radiation. 'Studies of the effects of such ozone reduction on human health have shown that a 5 per cent reduction in the amount of ozone in the atmosphere could cause between 20,000 and 60,000 additional cases of skin cancer in the United states alone' (A.N. Strahler and A.H. Strahler, 1977).

➤ Sulphur dioxide after combining with water films on suspended particulates forms poisonous fogs known as urban smogs over cities and industrial areas. Thus sulphur dioxide-originated smogs block the respiratory systems of human bodies and cause deaths of human beings. The ordeal of disastrous smogs of Donora (Pennsylvania, U.S.A., 1948), Meuse Valley (Belgium, 1930) and London (1952) has already been discussed in the preceding subsection.

➤ SO_2 (sulphur dioxide) pollution also causes diseases of eyes, throat and lungs. SO_2 causes instantaneous irritation of nose and throat when its concentration crosses the permissible limit of 10 ppm in the air for 8 hours of exposure.

➤ SO_2 pollution also causes acid rains which pollute the surface and subsurface water storage source and thus adversely affects the health of those persons who depend on such polluted water.

➤ Nitric oxide (NO) in high concentration in the air, when inhaled, combines with haemoglobine thousands of times faster than oxygen combines with haemoglobine and thus causes respiratory problem, gum inflamation, internal bleeding, oxygen deficiency, pneumonia and lung cancer. It may be pointed out that no definite results have been found out in relation to nitric oxides as the causative factor of above diseases in human bodies.

➤ Numerous suspended particulate matters (SPM) emitted from factories and automobiles during the combustion of fossil fuels (coal, petroleum and natural gas) and from other industrial processes, such as lead, asbestos, zinc, copper, dusts, etc. cause several deadly diseases in human bodies. Lead poisoning and asbestosis are among the deadly diseases caused by particulate air pollution.

➤ Sudden leakages of harmful and poisonous gases from chemical and gas plants pollute the air to such an extent that hundreds of people die within no time. Besides instantaneous deaths caused by poisonous gases, there are far reaching consequences of poisonous gases on future generations of human beings, micro-organisms such as bacteria, decomposers and fungi and thus environment is so greatly polluted that the ecological balance and ecosystem equilibrium is highly disturbed.

The **Bhopal Gas Tragedy** (Bhopal, India) of December 1984 is a burning example of one of the deadliest disasters caused by human negligence in the maintenance of deadly gases such as MIC gas (methyl iso-cynate). The leakage of MIC gas from the Union Carbide Factory at Bhopal on the wintry night of December 2/3, 1984 caused the single biggest air pollution tragedy which, according to official sources, claimed 2500 human lives in the early hours of December 3, 1984, whereas non-governmental sources put the figure beyond 5000. Methyl isocynate gas is produced at Bhopal based Union Carbide Factory of the USA to manufacture pesticides. The produced MIC gas is stored in underground containers. The poisonous MIC gas leaked from these containers and the leakage continued for 40 minutes. The poisonous gas was quickly spread in nearby densely populated localities of old Bhopal under the impact of morning breeze. According to the latest report the poisonous gas has claimed 3,410 human lives so far. Besides, hundreds of thousands of inhabitants were exposed to poisonous gas and thousands of animals were killed. The poisonous gas also polluted drinking water, soils, tank and pond water and adversely affected foetus, newly born babies, pregnant women, children, young and old people alike.

(3) Effects on Plants

The depletion of ozone caused by chlorofluorocarbons and nitrogen oxides, if not checked and corrected, would enormously increase ultraviolet solar radiation reaching the earth's surface. The increased ultra-violet solar radiation would adversely affect plant and animal communities in a variety of ways. Photosynthesis, water use efficiency and yields of plants would be substantially reduced. Soil-moisture would be significantly reduced and thus agricultural crops would weather away resulting into marked decrease in food production.

Photosynthesis by phytoplanktons in the marine ecosystems would be greatly reduced. Many phythoplanktons would die which in turn would adversely affect zooplanktons and other marine organisms which feed on phytoplanktons. Many of fishes would die because of want of their food in the form of phytoplanktons. Rise in the temperature of the earth's surface due to ozone depletion and increase in greenhouse effects of the atmosphere due to higher concentration of carbon dioxide and other greenhouse gases would affect the type, density and stability of vegetation which in turn would affect animal community and sediment and chemical element cycles.

The pollution caused by high concentration of sulphur dioxide adversely affects plant community. The studies have shown that lichens are more succeptible to sulphur dioxide and other air pollutants. All lichens die in the zones where the concentration of sulphur dioxide reaches the level of 170 microgram per cubic metre of air or more in U.K. The studies have further shown that the deciduous forests in the state of Tennessee in the USA and the evergreen forests of Black Forest in Germany are being gradually destroyed owing to sulphur dioxide pollution. Conifers like douglas fir and lodgepole pine in the USA are being adversely affected by sulphur dioxide pollution. In India mango is being badly affected by sulphur dioxide mainly near brick-kilns. Acid rain caused by sulphur dioxide is the main culprit of the destruction of vegetation community. Increased concentration of hydrogen fluoride causes necrosis, and discolouration of plant leaves.

6. CONTROL OF AIR POLLUTION

It is apparent from the aforesaid discussion that air pollution is the legacy of economic development, industrial growth, and urban expansion in the modern world. Some sort of air pollution cannot be avoided if we go for development but the development through industrial expansion can be beneficial only when air pollution control measures are also adopted. It is also evident that the control and abatement of air pollution in large urban centres and industrial areas of the world would require a substantial financial investment as well as changes in the patterns of living and energy use. 'It is unrealistic to speak of no air pollution whatsoever, it is virtually impossible to eliminate entirely all man made emissions of foreign gases and particles into the atmosphere. It is more sensible to aim at the reduction of the pollutant emissions to a point so that serious adverse effects associated with the presence of pollutants in the air are eliminated. Because of huge expenditure of money that will be required, social and political factors will play a major role in meeting this goal' (B.N. Singh, 1983). The following ambient air quality standards should (table 21.4) be taken into account before implementing any pollution control measures.

Table 21.4 : Ambient air quality standard

Pollutants	Ambient Standards
Carbon monoxide (CO)	Primary standard-10 milligrams per cubic metre of air (9 p.p.m.) on a maximum 8-hour concentration, not to be exceeded more than once a year. Secondary standard-40 miligrams per cubic metre of air (35 p.p.m.) as a maximum one-hour concentration.
Photochemical oxidants	Primary and secondary standards-160 microgram per cubic metre of air (0.08 p.p.m.) as a maximum one-hour concentration.
Hydrocarbons	Primary and secondary standards-160 microgram per cubic metre of air (0.24 p.p.m.) as a maximum 3 hour concentration (6 to 9 A.M.).
Nitrogen oxides	Primary and secondary standards-100 microgram per cubic metre of air (0.05 p.p.m.) on an annual arithmetic mean.
Sulphur oxide	Primary standard-80 microgram per cubic metre of air (0.03 p.p.m.) on an annual arithmetic mean and 365 microgram per cubic metre of air (0.14 p.p.m.) as a maximum 24-hour concentration. Secondary standard-60 microgram per cubic metre of air (0.02 p.p.m.) on an annual arithmetic mean.
Particulate matter	Primary standard-75 microgram per cubic metre of air on an annual geometric mean and 260 microgram per cubic metre of air as a maximum 24-hour concentration. Secondary standard-60 microgram per cubic metre of air on an annual geometric mean.

Table 21. 5 : Summary of the 'pollutant standards index' (PSI)

Index	Air quality level	Pollutant levels (mg/m^3) carbom monoxide (8-hour concentration)	Health Effects
500	Significant harm	57.5	
400	Emergency	46.0	Hazardous
300	Warning	34.0	Very unhealthful
200	Alert	17.0	Unhealthful
100	National Ambient Air Quality Standard (NAAQS)	10.0	Moderate
50	50 per cent of NAAQS	5.0	Good

Source : J. Crossland, 1978 : 'Reporting Pollution', Environment, Vol. 20, pp. 29-31.

Since increasing air pollution in the developed industrialized countries and also in the developing countries is causing besides extensive physical damage to property mainly important buildings of historical importance, thousands of death of human beings every year and millions suffering from diseases of various types, air pollution has to be controlled at any cost. The air pollution control measures may involve the following steps :

- ➤ to create awareness among all walks of people in society and government bodies and officials towards the causes and effects of air pollution.
- ➤ to conduct extensive survey and regular monitoring of the existing level of air

pollution and to predict, on the basis of existing information, the possible level of air pollution and adverse effects imanating from it in near future.

- to acquaint the general public with the adverse effects of air pollution on their health and wealth.
- to make efforts to disperse and dilute the pollutants in the upper air to reduce their concentration at ground level.
- to reduce the total pollution load of the atmosphere.
- to eradicate extremely hazardous forms of air pollution which cause irreparable loss to human society.
- to make efforts to search alternative less harmful products such as solar-powered cars (as done recently in the U.S.A.).
- to improve the existing devices of air pollution control and to make efforts to invent new effective devices to control air pollution.
- to switch over from diesel driven buses and autorikshas to CNG driven vehicles in major cities as is followed in Delhi.
- to start metro-rails in major cities in India and other developing countries on the line of metro-rails in Kolkata and Delhi. It may be mentioned that efforts are made to run metro-rails in Mumbai, Channai, Bangalore, Hyderabad etc. in order the reduce the number of fossil fuels driven automobiles so that gaseous and particulate matter air pollution may be minimized.

It may be pointed out that comprehensive control measures of air pollution and air quality management strategy must be based on holistic perspective of air pollution involving different aspects of pollution, its impact on human society and overall environment such as time and place of air pollution, its impacts on human health, natural resources, ecosystem equilibrium, ecological balance, human needs, essential commodities like food, medicine, clothes, houses, transport, domestic products and above all costs of control measures. The immediate concern of human community is to reduce the emissions of chlrofluorocarbons, halogen, hydrocarbons, oxides of sulphur and nitrogen, carbon monoxide and greenhouse gases and particulate matter and smokes.

The following instrumental devices may be used to check air pollution through gaseous and particulate pollutants :

(1) The particulate matter coming out of 'human volcanoes' (chimneys of factories) can be checked and reduced to a much lower level by the use of following instruments :

(a) **Bag filter** : Bag filter is a filtering device which is used to filter and thus separate particulate matters from the industrial fumes. Several types of filters are used. Typical industrial filter used for separating particulate matters coming out with smokes from the chimneys is called bag filter. The fumes having particulate matters coming out of factory chimneys are allowed to pass through the cylinder wherein gases pass out of the cylindrical bag whereas particulate matters-dusts settle down.

(b) Particulate matters of size larger than 50 micrometre are filtered and separated by **cyclone separator** or **cyclone collector** and **wet scrubbers.** The cyclone separators or say collectors have been made on the basic principle of centrifugal action. The industrial fumes with particulate matters are allowed to pass through an opening (fig. 21.1) into a conical cylinder (a cylinder having conical base, see bottom portion of figure 21.1) where the fumes are whirled and chirned at desired speed. This device thus allows the solid particulate matters to settle down and pass out through narrow outlet fitted at the bottom of the cylinder (fig. 21.1) and the gas is allowed to escape through an opening fitted at the top of the cylinder. The **wet scrubbers** clean the gases by wetting them with water.

(iii) Particulate matters of smaller size (smaller than one micrometer) are effectively handled by **electroastatic precipitators** (ESP), **high energy scrubbers and fabric filters.** The electrostatic precipitators have been devised on the basic principle that smaller solid particulate matters emitted from the factory chimneys have electrical charges on their surfaces. Based on this characteristic feature of smaller dust particles pairs of opositely charged electrodes are fitted in a cover and the dust laden factory fumes are allowed to pass through these high voltage electrodes (fig. 21.2) where charged dusts are attracted and are forced to settle down. Ultimately the dust particles pass out through dust outlet fitted at the bottom and are collected there while dust free air passes out through the top outlet or gas exit. Though electrostatic precipitators (ESP) are costly but cost should not be considered because human lives are more important. Several other divices are used to control particulate and gaseous pollution of air as follows :

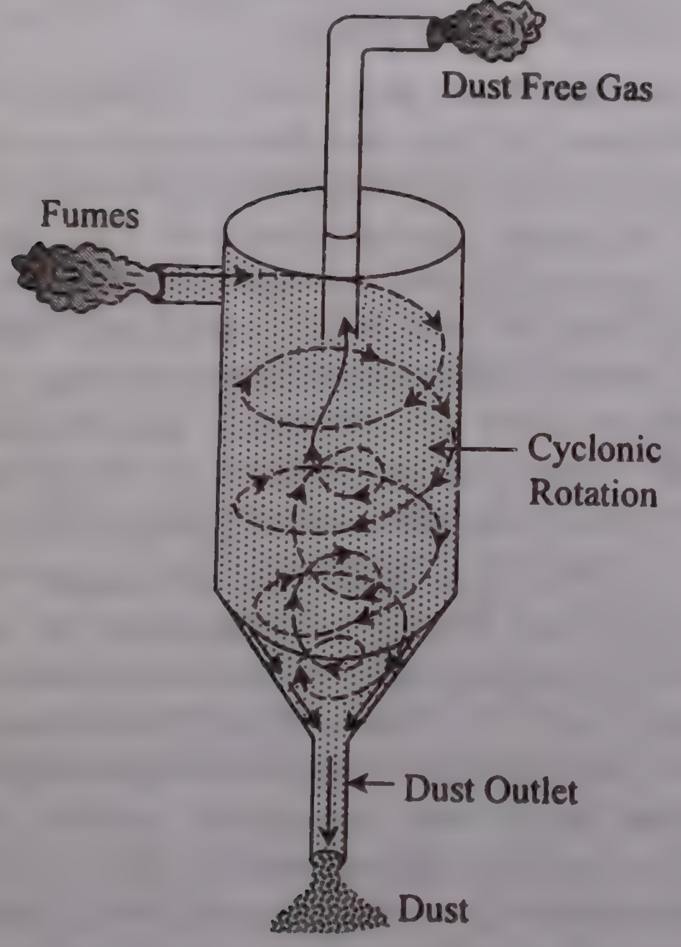


Fig. 21.1 : Cyclone Separator or Collector to clean industrial fumes having gases and solid particulate matters.

- Sulphur dioxide (SO_2) produced through the combustion of fossil fuels can be removed from stock gases by flue gas desulphurization (FGD) methods. Calcium oxide or lime (CaO) or calcium carbonate ($CaCO_3$) and magnesium oxide (MgO) or magnesium carbonate ($MgCO_3$) may be used to desulphurize sulphur dioxide.
- Combustion modifications may be adopted to control the emission of nitrogen oxides. For example, the combustion of coal below 55°C temperature produces low quantity of NO but combustion at 1650°C or more produces large quantity of NO emission.
- Combustion modifications may also be used to reduce the emissions of carbon monoxide (CO).

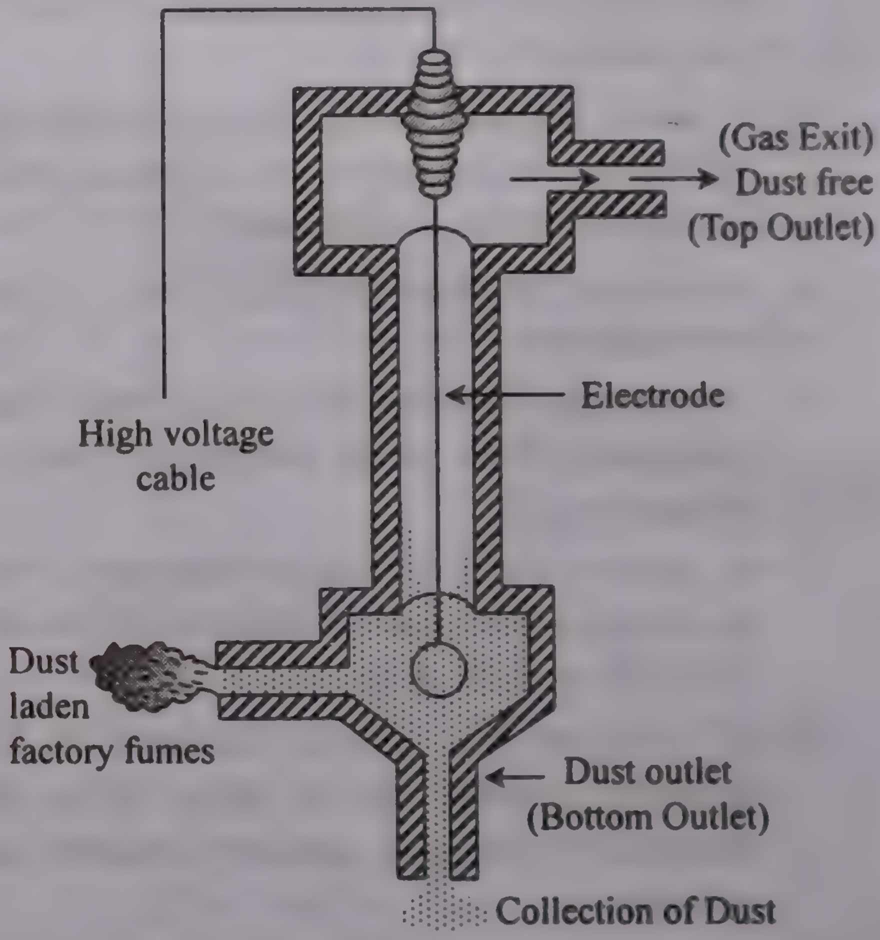


Fig. 21. 2 : Electrostatic Precipitator (ESP) to clean industrial fumes having solid particulate matters.

- Activated carbon powder is capable to absorbing many of the pollutants.
- The height of chimneys of the factories should be sufficiently raised so that ground concentration of toxic pollutants may be markedly reduced.
- Several mechanical devices should be used to reduce the emission of pollutant gases and solid and liquid particulate matters from automobiles particularly motor cars, buses and trucks and two and three wheelers. The air pollution caused by vehicles has assumed alarming proportion in the metropolitan cities of our country too, mostly in Delhi, Mumbai, Kolkata, Chennai, Kanpur, Hyderabad, Nagpur etc. The government of India is seized of the problem and has formulated Air Prevention Act and Control Bill (1981) to

check air pollution in the big cities of the country.

The Delhi administration has acquired several **exhaust gas anlysers.** Two mobile teams equipped with these instruments check vehicles on the roads. This team checked 1,40,650 vehicles upto August, 1989 and found that 37.9 per cent of these vehicles were emitting pollutants beyond the safety limits. Delhi's Transport Directorate has made it mandatory for commercial vehicles to undergo a pollution check. The Delhi Transport Corporation (DTC) central workshop and all the 33 depots have been equipped with smoke meters. It is surprising to note that even Delhi Transport Directorate could not acquire pollution controlling machinery like electrolytic convertors, which recycle exhaust and make it less harmful.

21.6 WATER POLLUTION

1. Meaning and Definition

Water is the most important element in the biosphere because on one hand it is vital for the maintenance of all forms of life and on the other hand it helps in the movement, circulation and cycling of nutrients in the biosphere. It is found in various phases and in various stroages such as (i) in liquid phase (storages such as rivers, lakes, seas and oceans, soils, living organisms etc.), (ii) in solid phase (storages such as glaciers and ice sheets and ice caps like ice caps of Arctic region, Greenland and Antarctica and mountain glaciers e.g. Alpine glaciers, Himalayan glaciers etc.). Water is also essential for power generation, navigation, irrigation of crops, disposal of sewage etc. It may be pointed out that only one per cent of the total amount of water of the hydrosphere is available to human beings and other biotic communities from various sources such as groundwater, rivers, lakes, soils, atmosphere and biological system but groundwater provides the largest amount of water. Increased demand of water consequent upon increasing population and industrial expansion has degraded the quality of water considerably. Though water like other natural substances has self purifying capacity during recycling processes but when the amount of the foreign undersirable substances added by the man to the water exceeds the tolerance level and self purifying capacity of water, it gets polluted.

Water pollution may be defined as 'alteration in physical, chemical and biological characteristics of water which may cause harmful effects on human and aquatic life.'

Report, 1965, Restoring the Quality of our
Environment, President's Science
Committee, Washington, USA.

'Foreign materials either from natural or other sources are contaminated with water supplies and may be harmful to life, because of their toxity, reduction of normal oxygen level of water, aesthetically unsuitable effects and spread of epidemic diseases.'

World Health Organization (WHO), 1966

Water pollution is defined as 'natural or induced change in the quality of water which renders it unsuitable or dangerous as regards food, human and animal health, industry, agriculture, fishing or leisure pursuits'.

P. Vivier, 1958

The term water pollution 'refers to deterioration in chemical, physical and biological properties of water brought about by human activities and/or by natural (e.g. hydrological) processes which induce decomposed and vegetable materials and weathering products of rocks etc.'

C.S. Southwick, 1976, Ecology and the
Quality of Our Environment, New York.

A Comprehensive definition of water pollution encompassing all aspects may be suggested as given below :

"Water pollutoin refers to deterioration of physical (such as colour, odour, turbidity, taste, temperature etc.), chemical (such as acidity, alkalinity, salinity etc.) and biological (presence of bacteria, coliform MPN, algae etc.), characteristics of water from various storages (such as river water, lake water, pond water, groundwater) through natural (e.g. fallout of volcanic dust, landslides near water bodies, sediments supplied by soil erosion and weathering processes) and anthropogenic (e.g. industrial, urban, agricultural, domestic, radioactive, mining sources etc.) processes to such an extent that it becomes harmful to human beings, plants and animal communities.

Savindra Singh, 1991

Sources of Water Pollutants

The substances which degrade the quality of water from its equilbrium state are called water pollutants which are generated from two basic sources :

(1) Natural sources of water pollutants, and

(2) Anthropogenic sources of water pollutants.

(1) **Natural sources** : of water pollutants include soil erosion, landslides, coastal and cliff erosion, volcanic eruption and decay and decomposition of plants and animals. Excessive soil erosion in the catchment area of a particular river increases the sediment load of the river and thus increases the turbity of river and lake (when silt-loaded river empties into a lake) water. Landslides near lakes pour down enormous quantity of debris into the lake and thus the lake is polluted not only through silting of its bed but also through increased turbidity.

(2) **Anthropogenic sources :** It may be pointed out that natural water system is capable of taking care of natural pollutants and therefore it is the anthropogenic sources which are the real sources of water pollution. The anthropogenic sources of water pollution include industrial source, urban source, agricultural source, cultural source (congregation of large number of people during pilgrimage, relegious fairs etc., for example, more than 30 million people from all over India congregate at the confluence of the Ganga and the Yamuna at Allahabad every 12 years during Kumbha Fair) etc.

Urban source contributes water pollutants such as sewage, huge quantity of muncipal and domestic garbages, industrial effluents from the industrial units located in the urban centres, fallout of particulate matter of automobile exhausts etc.

Various types of chemicals used in the chemical fertilizers, pesticides and herbicides etc. are the pollutants which are derived from agricultural sources. These chemical substances are brought to the rivers and lakes through surface runoff caused by rainfall and are also moved downward by infiltrating rainwater to reach groundwater.

Industrial sources pollute streams, rivers, lakes and coastal waters through industrial effluents, solid and dissolved chemical pollutants and numerous metals. Besides, fallot of radioactive substances is very dangerous source of air and water pollution.

3. Types of Water Pollutants

Water pollutants may be divided into certain categories on different bases such as sources of pollutants, physical and chemical properties of water, and the nature of degradation.

(1) On the basis of sources of pollutants

(a) **industrial pollutants**

examples : industrial waste water, including several chemical pollutants such as chlorides, sulphides, carbonates, ammonical nitrogen, nitrites, nitrates, heavy metals such as mercury, lead, zinc, arsenic, baron etc., organic chemical compounds synthesized for industrial purposes, radioactive wastes etc.

(b) **agrilcultural pollutants**

examples : chemical fertilizers, pesticides, insecticides and herbicides, and several other synthetic chemical compounds, weeds and plant remains.

(c) **urban pollutants**

examples : various types of ions such as sulphate ion, nitrate ion (representing washout of air pollutants emitted from automobiles and other forms of combustion of fossil fuels), chlorine ion, and sodium ion (coming from deicing salts used to melt ice spread over roads and streets in cold countries), calcium ions and bicarbonate ions (from lime and chemical fertilizers used in the lawns and gardens within the cities), sulphate, nitrate and potassium ions, a host of chemical ions contained in urban sewage water, household sewage stored in the septic tanks, phosphate and nitrate ions, wastes of human and animals etc.

(d) **natural pollutants**

examples : volcanic dusts, eroded and weathered sediments, debris caused by landslides, decayed and decomposed organic matter (both plants and animals).

(2) **On the basis of physical and chemical properties**

(a) **physical pollutants**

examples : colour, taste, turbidity, sedimetns, volcanic dust, oil and greese, dissolved and suspended solids, total solids.

(b) **chemical pollutants**

examples : chlorides, sulphides, carbonates, ammonical nitrogen, nitrates, nitrites, pesticides, insecticides, heribicides, several other synthetic chemical compounds.

(3) **On the basis of degradability**

(a) biodegradable pollutants

(b)non-biodegradable pollutants

Those pollutants which are broken down and decomposed by biological means such as decomposers/ micro-organisms are called biodegradable or simply degradable pollutants. These pollutants are also called as organic pollutants. Nondegradable pollutants are those which cannot be degraded by biological means. Such pollutants are also called as inorganic pollutants. Examples of biodegradable or organic pollutants are leaf litters, sewage, garbages, plants and animals, human and animal excreta etc. Non-degradable pollutants include all of the chemical pollutants and toxic solid substances.

4. Nature of Water Pollution

'The nature and intensity of water pollution is linked with many factors like waste water disposal and treatment system, hydrological conditions of diluting bodies and self-purification capacity of the streams, characteristics of effluents discharging from an area, socio-economic conditions of the communities generating the wastes and, in cases, types of soil and vegetation' (J. Singh and D.N. Singh, 1988). Even rainwater is never pure because when it falls as rainfall, atmospheric carbon dioxide is mixed with it and thus acidity of rainwater is slightly increased because of dissolution of atmospheric CO_2 in rainwater. When rainwater passes through several pathways such as lateral movement as surface runoff and downward movement as groundwater several contaminants mix with the water. Further, a host of pollutants are discharged from various sources e.g. industrial, urban and agricultural into different water storages such as river water, lake water, pond water and groundwater. All these pollutants pollute the water to various levels depending upon the nature, and amount of pollutants. It is significant to point out that unlike air, water has dissolving capacity and therefore water, while moving through various pathways, further dissolves several chemical substances and thus is further polluted by numerous organic and inorganic matters.

The water pollution is assessed on the basis of certain parameters e.g. (i) physical, (ii) chemical, and (iii) biological parameters. Physical parameters used to ascertain the quality of water include temperature, colour, odour, turbidity, conductivity, density, suspended, dissolved and total solids while chemical parameters include nature and amount of soluble salts, hardness of water, acidity and alkalinity of water, dissolved oxyengen (DO), biological oxygen demand (BOD), chemical oxygen demand (COD), concentration of hydrogen ion (pH), amount of ammonia, nitrate and nitrites, amount of heavy metals, mecrury, lead, chromium, chlorides, pesticides, insecticides, detergents etc. Biological parameters are bacteria, coliform MPN, algae, viruses etc. Generally, Biological Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Dissolved Oxygen (DO), and pH value are important indicators of water quality.

5. Types of Water Pollution

Water pollution may be divided on the basis of sources and stroages of water into the following 4 categories :

(1) Surface water (river water) pollution,

(2) Lake water pollution,

(3) Groundwater pollution, and

(4) Sea water pollution

Water pollution may also be divided on the basis of sources of water pollution into the following 4 types :

(1) Sewage water pollution,
(2) Domestic waste water pollution,
(3) Industrial waste water pollution, and
(4) Solid waste water pollution.

SURFACE (RIVER) WATER POLLUTION

1. Nature of River Water Pollution

Surface water includs river water, lake water and pond (tank) water but here only river water pollution is being discussed as lake water pollution will be discussed under a separate heading. Surface river water is polluted through the mixing of diferent quantities of dissolved inorganic matter in the form of ions (positively charged ions= cations, and negatively charged ions=anions). It may be poined out that the major source of surface water is precipitation which contributes water to surface storage through rainfall and melt-water. 'All surface water and all groundwater, no matter how "pure" it seems to us as a drinking water, contains a variety of ions in solution......The ions naturally present in freshwater of the lands are mosly of inorganic class, meaning that they are all originally derived from non-living sources. Inorganic sources are (1) the atmosphere, (2) ocean water, and (3) soil, regolith, and bedrocks. Ions move through rather complex pathways following the hydrologic cycle' (A.N. Strahler and A.H. Strahler, 1977).

2. Pollutants of River Water Pollution

Fresh rainwater, considerd as 'pure' water in general public, is seldom pure as it contains numerous ions from different sources viz. ions of sulphate (SO_4^-), chlorine (CL^-), sodium (Na^+), magnesium (Mg^{++}), calcium (Ca^{++}), and potassium in those areas which are free from industrial and urban influences. These ions reach the atmosphere to join rainwater from land, soil, regolith, bedrock and ocean water. In addition to the aforesaid ions which are added to the rainwater from natural sources some new pollutants are also added to the rainwater when it comes in contact with the land surface e.g. fresh input of chlorine ion and sodium ion from deicing salts (salts are used to melt ice mainly from roads in the countries of cold climates); calcium and biocarbonate ions from the use of lime and fertilizers; sulphate, nitrate, potassium and magnesium ions from chemical fertilizers. Besides these pollutants, there are other contaminants which pollute surface waters whether moving (river) or stagnant (lakes and ponds and inland seas) such as (i) pesticides, which are used to remove unwanted weeds from crops and to prevent plants diseases; (ii) toxic metals such as lead, mercury, cadmium, zinc, asbestos etc.'; (iii) radioactive wastes from the processing and use of nuclear fuel etc. These pollutants reacting with other chemical substances introduce several types of chemical and physical changes in surface waters and thus contaminate and polluted waters adversely affect plants and animals including man. For example, combustion of fossil fuels (coal and petroleum) in the power plants, factories and automobiles releases sulphur dioxide (SO_2) which after reacting with water films forms sulphuric acids (H_2SO_4). These sulphuric acids come down on the earth's surface with precipitation as acid rains. Acid rains increase the acidity of surface water and reduce pH of soil water and also surface waters.

US. Department of Health, Education and Welfare (HEW) has classified pollutants of surface water pollution into 8 major categories as follows :

(1) **Sewage wastes** include numerous chemical substances brought down by the sewage drains of urban and industrial areas as referred to above.

(2) **Infectious agents** include germs and viruses which cause several types of diseases such as typhoid, dysentry, cholera, malaria, tubercluosis, jaundice etc.

(3) **Plant nutrients and disolved substances eg..** chemical fertilizers, detergents, animal and human wastes.

(4) **Particulate matter** e.g. soil and mineral particles.

(5) **Radioactive substances** released from nuclear reactors.

(6) **Mineral and chemical substances** coming from modern industries and mining operations such as salts, acids, oil and greases etc.

(7) **Heat** : in the form of hot water released from chemical and metal industries, electrical power plants run with atomic energy, coal, petroleum and natural gas.

(8) **Organic chemical exotics** such as synthetic materials like pesticides, insecticides, herbicides, rodenticides etc.

3. Sources of River Pollution

The major sources of river water pollution are industries, urban centres, agriculture and other human activities. Discharges of urban sewage water, industrial effluents carrying industrial waste water, washing and dumping of industrial solid wastes, non-degradable and long lasting pollutants from leather tanneries, sugar factories, beet-sugar refining, meat-packing, distilleries etc. into nearby rivers pollute the water of streams, rivers and 'nalas'.

Types and Causes of River Pollution

River water is polluted in two ways as follows :

(1) Point pollution, and

(2) Non-point pollution.

The main sources of **point pollution** of river waters are industries and urban centres wherein pollutants are discharged into the rivers through urban sewage drains and industrial effluents at specific points (outfall points) at the river banks. **Non-point pollution** of river water involves discharge of pollutans mainly from agricultural fields through surface runoff. Rainfall generates surface runoff which removes chemical substances from the land applied to the agricultural fields in the form of chemical fertilizers, pesticides, insecticides and herbicides and transports them to nearby rivulets, streams and rivers. Huge amount of sediments caused by accelerated rate of soil erosion effected by human activities (such as deforestation) reaching the rivers is major source of nonpoint pollution of river water because these sediments increase the sediment load of the rivers and thus increase turnbidity of the water.

Increasing urbanization and industrial expansion are responsible for the release of enormous quantities of pollutants of various kinds (as referred to above) through sewage effluents into the rivers and lakes and thus contaminating the water beyond permissible safety level. The following examples dentote the nature of water pollution in India.

(1) Most of the Indian rivers receiving urban and industrial effluents (wherever large cities and industrial complexes are located at or near the banks of the rivers) are heavily polluted due to point-pollution at least at and downstream of the large cities and industrial centres. For example, the **Yamuna river** at Delhi has, in fact, become a sewage as 323 million gallons of sewage enter the Yamuna per day through 17 open drains, while the capacity of all treatment plants of the Municipal Corporation of Delhi (MCD) is only 184 MGD (million gallons per day). The toxic effluents discharging into the Yamuna carry 125,000 kg of BOD (Biological Oxygen Demand), 250,000 kg of dissolved solids and 125,000 kg of suspended solids per day. 'Before the Yamuna enters the capital, 100 millilitres of its water contain more than 7500 disease casuing bacteria but after receiviing Delhi's share of sewage, carry 24 million bacteria according to pollution control expert'. The study conducted by D.S. Bhargava of Roorkee University showed that the quality of water of the Yamuna was inferior downstream Delhi, Mathura and Agra where the water quality index (the scale ranging between 100 for the best water and 0 for the worst water) was 27,14 and 11 respectively (N.I.P., February 19, 1982).

(2) The contamination of streams in Medak district of Andhra Pradesh from the effluents of chemical plants presents the haunting spectrum of hazardous polluton caused by human activities. The Patancheru industrial belt, 30 km away from Hyderabad city, houses 300 industrial units at a place. This is perhaps the biggest concentration of industries at one place in the country. There are 50 chemical factories of which 23 are identified as dangerous. These industrial units do not have their own pollution treatment plants, with the result these used to discharge poisonous chemicals and toxic wastes into Chinnavagu, Peddavagu and Nakkavagu streams (the first two being the tributaries of the last one) leading to high level pollution of these rivers. The pollution of these three rivers affecting 14 villages along 22 km course of these three streams became so acute and assumed so alarming proportion that it became the head line of several local and national news papers and magazines-in the month of September, 1988. The Hindu, a leading national news paper of the country, reported the specter of pollution in Medak district on September, 18, 1988 as givne below :

"The reporter found the Vagu's waters coloured with chemical wastes and its margins distinctively marked by patches of greasy surfaces. A group of passing royts (Indian peasants), standing on the two-vent bridge across the stream, closed their nostrils to ward off the odious chemical odour

that bleow over the serpentine stream amidst fields from the nearby chemical factories".

The Hindu, September, 18, 1988

The toxic chemicals and poisonous waste waters seeped into the subsoils leading to contamination of both surface and subsurface (groundwater) water in 14 villages around the congested polluting industrial belt at Patancheru. The surface and groundwates (of dugwells and hand pumps) became green due to heavy concentration of chemical pollutants. Several animal deaths were reported in 1988 because they drank water from highy polluted streams as referred to above. Several cases of irritation in the eyes, sores and periodic diarrhoea were reported among rural folk. The residents had to abandon the use of water either from streams or wells for their domestic uses. The industrial units were asked to dump their wastes at municipal corporation's dumping compostyard at Amberpet till the common treatment plant could be obtained.

(3) Brief descriptions of seriously polluted rivers of India such as the Ganga river, the Yamuna river, the Damodar river, the Subarnarekha river, the Betwa river, the Periyar river, the Noyal river, the Bhawani river, the Cauvery river, the Goddawari river, the Krishna river and the Bhadar river have been given in chapter 25 (environmental degradation and pollution in India).

LAKE AND SEA WATER POLLUTION

Lakes are polluted through natural and anthropogenic sources. Siltation of lakes due to dumping of enormous quantities of sediments derived through accelerated rate of soil erosion caused by rapid rate of deforestation in hilly source areas of the streams is the major form of anthropogenic source of lake pollution. Numerous lakes in the Kumaun Region of Uttarakhand (India) have disappeared or are near extinction due to increased rate of weathering and erosion consequent upon reckless felling of trees. A few names of lakes such as 'Sukha Tal' (dry lake), 'Saria Tal' (rotten lake) etc. denote the level of pollution of lakes in Kumaun Region. The discharge of organic waste matter from the hill slopes surrounding the Nainital lake from all sides and toxic effluents from the urban area has polluted the lake water to such an extent that the fish mortality has risen to 80,000 to 100,000 per annum. Most of the artificially created reservoirs/lakes behind major dams or big rivers are facing the acute problem of siltation and resultant reduction in their water accommodating capacity.

Washing and dumping of tailings or **waste sludges** from factories into stagnant water of lakes and tanks pollute them more than they pollute the rivers because the river water is mobile while the lake water, in most cases, is stagnant. If the concentration of a single matter becomes very high, it may become a killing factor and the water so contaminated may turn into 'killer water'. For example, recrease in the concentration of asbestos in the lake water causes lung cancer in human beings and the killer disease is called **'asbestosis'**. The dumping of tailings as waste matter coming out of the production of iron ore pelletes by the Reserve Mining Company into Silver Bay, Lake Superior (USA) at the rate of 67,000 tons per day since 1947 caused a serious problem of pollution of lake water which could be realized only in 1968 when floating asbestos fibres on water surface were considered to be the main factor of lung cancer among the residents of Duluth, about 50 miles (80 kilometres) away from the source of pollution (dumping site of tailings by Reserve Mining Company). Consequently, the dumping of tailings was stopped in 1968 but soon after production was again started. The National Water Quality Laboratory in Duluth (NWQL), a research wing of the Environmental Protection Agency (EPA), also confirmed in 1973 the presence of large number of asbestos fibres in Duluth's drinking water and correlated these asbestos fibres with lung and stomach cancer.

Inorganic nutrients from the agricultural fields are also brought to the lakes by surface runoff, rivulets, streams and rivers. Besides, nitrates, phosophates and organic matters are contributed by sewage treatment plants. Similarly, toxic chemicals from factories enter the lake water. The abundance of nutrients causes uncontrolled growth of plants and animals while increased concentration of toxic chemicals causes deaths of aquatic organisms resulting into considerable decrease in lake populations.

Acid rains, the outcome of increased emission of sulphur dioxide (SO_2) from man-made sources (combustion of fossil fuels and automobiles) pollute lakes in the nearby regions of such factories. For example, the oxides of sulphur and nitrogen spewed from numerous mills in Germany and U.K. have caused widespread acid rains in Scandinavian countries (Norway, Sweden) with the result most of the lakes in Norway and Sweden have lost their biological communities and are now biologically termed as **'dead lakes.'**

In fact, acids rains are very often called as **'lake killers'** in Anglo-American and West European countries because they have been identified as main factors of **'death of lakes'** which means destruction and death of all aquatic lives including plants and animals in lakes, ponds and rivers. Out of 250,000 lakes of the state of Ontario (Canada), 50,000 have been adversely affected by phenomenal increase in the acidity of water and significant lowering of pH due to acid rains. Out of these lakes 140 have been declared as **dead lakes.**

SEAWATER POLLUTION

Sea water is polluted mostly near the coast through the disposal of urban and industrial waste matters into the coast water. Concentration of a single matter in the littoral water causes serious environmental problem. For example, concentration of mercury in the Minamata Bay (Japan) due to dumping of mercury-rich sludeges from Minamata city into the bay caused severe mercury poisoning. The resultant disease known as **Minamata Disease** claimed several lives in the city of Japan in early 1950s. Dumping of industrial wastes, urban effluents and toxic chemicals into the coastal water leaves adverse effects on many marine organisms. Many of the corals are reported to have been killed off the Andman and Nicobar coast (islands in the Bay of Bengal, India) because of toxic industrial effluents. Fishes are mostly adversely affected due to sea water pollution.

Source of Marine Pollution

1. Runoff and point discharge	44%
2. Air Pollution	33%
3. Shipping	12%
4. Dumping	10%
5. Offshore oil and gas production	01%

Source : Down to Earth, 15 Jan, 1998.

Endangered Coral Reefs by Marine Pollution

South-East Asia	30%
Pacific Ocean	25%
Indian Ocean	24%
Caribbean Sea	09%
West Asia (including Red Sea)	06%
Atlantic Ocean	6%

Source : Down to Eart, Jan 15, 1998

Leakage of immense quantities of crude oils from oil tankers and offshore oil wells is a major source of sea water pollution. On an average about 284 million gallons of mineral oil are leaked every year from the oil tankers. A few examples of leakages of immense quantites of crude oil from the oil tankers such as leakage of 100,000 metric tons of oil into sea from the Torry Canyon disaster off the coast of Cornwall, England in 1967; spillage of 10,000 metric tons of oil into the ocean from Santa Barbara accident in 1969; leakage of about 100,000 tons of crude oil from the wreckage of tanker vessel **Urquiola** near the Spanish coast La Coruna on May 12, 1976 etc. reveal the nature of environmental hazards produced by human activities such as leakage of crude oils form oil tankers. Such oil disasters also occur off the Mombai coast from the offshore oil wells. For example, one such accident took place near Mombai High on July 30, 1982 when ONGC (Oil and Natural Gas Commission) suffered a loss of Rs. 900 million involving damage of drilling rigs and precious crude oils. A major oil disaster from Mumbai High occurred on July 30, 1987 when a big oil tanker of Union Oil Company leaked 117,000 tonnes of crude oil into the sea.

Leaked crude oil rapidly spreads on water surface as **'oil slicks'** and makes the water poisonous, with the result numerous sea organisms including invaluable fishes die. Thus oil leakage causes ecological disaster in the coastal ecosystem.

GROUNDWATER POLLUTION

Groundwater is polluted through a variety of sources viz. leaching and downward movement of pollutants from agricultural field (such as nitrates, phosophorous, potash and several insecticides and pesticides), from industrial dumping areas, from urban and rural garbages, from earthen septic tanks and from polluted ponds and tanks. The main controlling factors of groundwater pollution are lithological characteristics of sub-soils and subsurface materials, depth of water table of groundwater, nature of aquifer, amount and nature of annual rainfall, general outlook of society, nature and rate of infiltration of rainwater and stagnant pond and tank water and above all the nature and amount of pollutants.

The loose and friable sandy soils, high water table and moderate to high annual rainfall accelerate the rate of infiltration of rainwater and rapid downward movement of pollutants with percolating water and consequently high rate of pollution of groundwater is the ultimate result. Generally, industrial wastes including waste water are dumped, where streams are not available in the nearby areas, into ponds or dug-out tanks. The dissolved chemical polltans are moved downward with percolating water (the process known as leaching) to meet the groundwater resource and thus groundwater is polluted which is readily reflected in the polluted water of dug-wells. Similarly, pollutants are leached downward from the municipal dump sites of city garbages. Leaching of polluting ions from the earthen soak pits and septic tanks and rotten and damaged underground sewer pipelines downward very often pollute groundwater up to a depth of 400 m. The pollutants which move downward with percolating water are called **leachates**. The leached pollutants are seldom stationary in the groundwater rather they move in the aquifers with the movement of groundwater as guided by groundwater contour.

Several cases of pollution of groundwater mainly the water drawn up by hand pumps and from wells have been reported almost from all countries of the world whether developed or developing. Pollution of well water was reported as back as 1832 in the USA when 3500 people were killed in New York City because of cholera due to the use of polluted water. The United States of Geological Survey found high content of sulphate, chloride and nitrate in the water of dug-wells of Crosby town in North Dakota (USA) during 1960s. The contaminated well water carried more than 4 times the limit of dissolved solids recommended by the Public Health Service of the USA for drinking water (A.N. Strahler and A.H. Strahler, 1977). The wells were contaminated by sewage wastes. The incident of pollution of groundwater due to toxic chemicals discharged by Patancheru industrial complex, about 30 kilometres away from Hyderabad city, in Medak district of Andhra Pradesh (India) is a buring example of pollution of groundwater by huamn activities. The toxic water discharged from 300 industrial units (50 being chemical factories) has speeped into the subsoils leading to contamination of both surface and sub-surface (groundwater) water in 14 villages around Patancheru industrial complex. The groundwater became greenish in colour and was so polluted that one started vomiting or felt like vomiting at the time of drinking it.

Undergound cavities caused by excessive pumping of water from groundwater reserves in the cities located near the sea coast result in contamination of groundwater because of leakage of saline sea water into the cavities. The example of Brooklyn (Kings county, New York, USA) city, located at the sea coast, is sufficient to demonstrate the environmental impacts of groundwater withdrawal on contamination of precious groundwater resource. The pumping of water from beneath the ground surface in Brooklyn city for urban residents at the rate of 75 million gallons per day resulted in the formation of big cavity of 5-mile diameter reaching a depth of 35 feet below sea level benath the city, consequently saline sea water leaked into the cavity and the wells became polluted due to salty water which forced the city authorities to close down these contaminated wells.

5. EFFECTS OF WATER POLLUTION

Water pollution causes irreparable damage to both plants and animals including man. The most sufferers are human beings and micro-organisms. Polluted water is the major cause for the spread of epidemics and several dangerous diseases such as cholera, tuberculosis, jaundice, dysentry, typhoid, paratyphoid, diarrhoea etc. The use of water polluted with solid minerals for drinking purpose causes fatal diseases. For example, the consumption of water contaminated by fibres of asbestos causes lung cancer and stomach diseases called as **asbestosis**, water polluted with mercury causes minamata disease etc. Water pollution mainly caused by toxic chemicals causes deats of aquatic organisms including both plants and animals. The use of polluted water of rivers, lakes and ponds and even polluted groundwater for irrigating agricultural fields severely damages crops and decreases agricultural production. Heavily polluted water also pollutes soils, decrease their fertilty and kills soil micro-organisms such as useful bacteria. The use of water, polluted by high concentration of sand load, for irrigational purposes increases the sand ratio of soils and thus reduces soil fertility and raises water requirement of the soils. The use of water contaminated with salts increases alkalinity in the soils. Rise in the concentration of inorganic and organic nutrients in lake and river waters causes **eutrophication** which leads to rapid rate of increase in the populations of plants and animals in the aquatic ecosystems beyond controllable limit. On the other hand, phenomenal increase in the concentration of toxic chemicals and harmful metals in different water bodies causes elimination of plants in general and animals in particular due to their sudden death. Contamination of sea water due to oil slicks resulting from leakage of crude oils from huge oil tankers and due to discharge of industrial and urban wastes causes ecological disasters in the littoral ecosystems because of mass deaths of sea organisms including fishes.

The adverse effects of water pollution may be summarized as follows :

- The use of polluted water for drinking purpose causes epidemics (such as cholera) and several dangerous diseases such as cholera, tuberculosis, typhoid, jaundice, dysentry, paratyphoid, diarrhoea etc.
- Water polluted with high concentration of certain trace mierals causes stomach disorders and cancer mainly in hill areas (such as in Uttrakhand), sclerosis (hardening of tissues and arteries of human bodies) etc.
- Water contaminated by fibres of asbestos, when used by humans, causes asbestosis, a form of lung cancer whereas water loaded with the concentration of lead beyond permissible limit causes lead poisoning. The water polluted with mercury causes minamata disease in humans.
- Higher concentration of arsenic matter causes severe skin disease as happens in Kolkata and its environs.
- Heavy concentration of toxic chemicals in water (of rivers, lakes, groundwater etc.) causes death of aquatic organisms, both plants, animals and micro-organisms.
- Water polluted with higher concentration of sulphuric acids, an outcome of rainwater, causes destruction and deaths of organisms in lakes and ponds as happens in Norway, and Sweden of Europe and Ontario of Canada.
- Heavy conentration of organic and inorganic nutrients in ponds, lakes and rivers causes eutrophication.
- The use of river water with high concentration of sand load for irrigation purposes reduces soil fertility and raises water requirement of soils.
- Water having higher concentration of salt content increses alkalinity of soils.
- Sea water polluted with oil slicks causes ecological disasters in the marine littoral ecosystems because of mass deaths of marine organisms including fishes.

6. CONTROL OF WATER POLLUTION

Control of water pollution requires several remedial measures involving individuals, community, governments at national and international levels as follows :

- The individuals must be educated enough to understand the nature of water pollution and its adverse effects on human health and wealth.
- There must be mass awareness and correct perception at community level about various aspects of water pollution.
- People must restrain themselves from throwing human and animal excreta and garbages into any water body.
- Industrial units and municipal corporations must arrange for sewage treatment plants and treat polluted water before discharging effluents into lakes and rivers.
- Government should provide adequate funds to the municipal corporations for making water pollution control more effective.

- Government must bring in force effective laws for water pollution control measures.
- The individuals, communities, officials and the owners of mills must be tried in the courts of law and suitably penalized under strict laws, if they violate the provisions of pollution control.

The problem of water pollution has already assumed alarming proportion in many large cities and industrial complexes in India such as in Delhi, Kanpur, Varanasi, Kolkata, Mumbai, Chennai etc. Even small towns of India suffer from high level of water pollution mainly surface water pollution because of open earthen sewer drains, service latrines, uncovered earthen septic tanks and soak pits, improper drainage systems and frequent water logging. Orthodox religious faiths are also adding fuels to the problem of river water pollution. For example, inspite of the provision of electric crematorium in several big cities at the bank of the Ganga (such as at Kanpur, Allahabad, Varanasi etc.) people still burn dead human bodies with wood and throw half burnt wood, ash and human bodies in the Ganga in the faith that by doing so the departed soul would be seated in the heaven.

The government of India has already taken initiative in controlling water pollution by passing the Water (Prevention and Control of Pollution) Act in 1974. This water pollution prevention and control Act aims at the maintenance of good water quality for human use. It may be pointed out that government of India was seized of the problem of water pollution even in late 19th century as is evident from the enactment of the following Acts regarding the control of water pollution. Important Water Acts are given below while detailed aspects of water Acts in India have been given in chapter 26 of this books.

Central Water Control Acts

(A) Before Independence

1. The North India Canal and Drainage Act, 1873
2. The Obstruction of Fairways (navigable channel) Act, 1881
3. The Indian Fisheries Act, 1897

(B) After Independence

4. The Damodar Valley Corporation (Prevention of Pollution of Water) Regulation Act, 1948
5. The River Boards Act, 1956
6. The Merchant (Amendment) Shipping Act, 1970
7. The water (Prevention and Control of Pollution) Act, 1974
8. The Water (Prevention and Contol of Pollution) Cess Act, 1977
9. The Water (Prevention and Control of Pollution) Cess Rules, 1978.
10. The Coastal Regulation Zone Notification, 1991, puts regulation on various activities, including construciton. This notificaiton offers protection to natural buffers, such as backwaters, estuaries, corals, mangroves, beaches and coastal dunes.

The government plans to clean the Ganga and the Yamuna under the Ganga Action Plan (GAP) and the Yamuna Action Plan (YAP) would be discussed in Chapter 25 of this book.

21.7 LAND/SOILS POLLUTION

Here land simply means the surficial parts of lithosphere wherein soil is the most significant aspect of land surface for biological communities. This is why soils are termed as **'biological reservoirs'** or **'biological factory'**. Land degradation simply means loss of utility of land for plants and animals. Though some natural factors such as climatic changes (e.g. desertification and desert spread, conversion of warm land into cold land-icecovered surfaces etc.), volcanic eruption and lava flow, orogenesis etc. cause land degradation but anthropogenic factors are mostly responsible for land degradation and pollution world over. The following human activities degrade land surfaces :

- mining activities,
- massive deforestation,
- overgrazing,
- global warming resulting into desert spread,
- major land use changes,
- heavy canal irrigation,
- construction and building activities,
- discharge of sewage or waste water from industrial and urban areas on to the land used for agricultural purposes,

- irrigation of agricultural fields with polluted water,
- soil pollution etc.

In fact, **soil pollution** is the major form of land degradation and pollution and hence it requires detailed discussion.

Soils are in fact the very heart of the life layer (the biosphere) because these represent a zone wherein plant nutrients are produced, held, maintained and are made available to plants through their roots and to the micro-organisms which live in the soils. Soil is also very important environmental attribute for human society because :

- It is the basic medium for food and timber production.
- It is very exhaustible natural resource because it cannot be replaced if it is destroyed or lost through excessive soil erosion caused by anthropogenic activities and it is the base for the evolution and development of human civilization.
- It provides foundation for buildings and roads.

The formation of soil is a slow process as the formation and development of one inch of soil requires about one thousand years wheras the destruciton of soils through erosion and pollution is quick process. The quality of soils depends upon the nutrients (both organic and inorganic), humus content, moisture, temperature etc. present in the soils. Various aspects of soils such as components of soils, soil texture, soil structure, soil profiles and horizons, and classification of soils have been discussed in the 7th chapter of this book.

Soil Pollution : Definition

Decrease in the quality of soils either due to anthropogenic sources or natural sources or by both is called **soil pollution or soil degradation**. Decrease in the quality of soils is caused due to accelerated rate of soil erosion, decrease in plant nutrients, decrease in soil micro-organisms, excess or deficit of moisture content, high fluctuation of temperature, lack of humus content and input and concentration of various types of pollutants.

Factors of Soil Pollution

The main factors of soil pollution are accelerated rate of soil erosion consequent upon major land use changes (e.g. deforestation); excessive use of chemical fertilizers, pesticides, insecticides and herbicides; polluted waste water from industrial and urban areas; a few micro-organisms; forest fires; dumping of urban and industrial solid wastes; water logging and related capillary process; leaching processes; drought etc.

Sources of Soil Pollution

The sources or agents of soil pollution may be divided into the following 5 categories :

- (1) physical agents/sources,
- (2) biological agents/sources,
- (3) air-born sources,
- (4) biocides and chemical fertilizers, and
- (5) urban and industrial sources.

(1) **Physical source** of soil pollution is related to soil erosion and consequent soil degradation caused by natural and anthropogenic factors. The natural factors of soil erosion include amount and intensity of rainfall, temperature and wind; topographic factors; lithological factors; vegetation and soil characteristics. These factors are further accelerated by human activities such as land use changes (e.g. deforestation). In most of the developing countries of the tropical and subtropical regions accelerated rate of soil erosion due to rapid rate of deforestation and faulty agricultural practices has degraded the soil on a large-scale because the top fertile layer has been washed out. Various aspects of soil erosion e.g. facets of soil erosion, mechanics and forms of soil erosion, factors and causes of soil erosion, regional pattern of soil erosion and conservation measures of soil erosion have been discussed in the 16th chapter of this book.

(2) **Biological sources** or agents of soil pollution include those micro-organisms and unwanetd platns which degrade the quality and therefore fertility of the soils. The biological agents of soil pollution are grouped into 4 major categories :

- pathogenic micro-organisms excreted by human beings,
- pathogenic micro-organisms excreted by domestic animals,

- pathogenic micro-organisms already present in the soils, and
- enteric bacteria and protozoa.

The micro-organisms enter the soils from various sources and degrade them. These micro-organisms also enter the food chains and thus affect human bodies.

(3) **Air-born sources** of soil pollutants are, infact, air pollutants which are released into the atmosphere by 'human volcanoes' (chimneys of factories), automobiles, thermal power plants and domestic sources. In fact, gaseous and solid particulate pollutants emitted by factory chimneys and other sources are transported to the areas far away from the source of the emission of pollutants by prevailing wind. The fallouts of these pollutants are deposited in the soils which are polluted due to toxic substances. Sulphur emitted from the factories causes acid rains which lower the pH of the soils. Acid rains increase the acidity of the soils. Highly acidic soils are injurious to plant growth. Sulphur dioxide (SO_2) emitted from the factories in U.K. and Germany has been responsible for widespread acid rains in the Scandinavian countries (Norway, Sweden, Finnald) wherein substantial decrease in soil pH and increased soil acidity have largely damaged forest resources. Similarly, the pH of the soils of maritime provinces of Canada (Quebec and Ontario) have been markedly decreased because of acid rains caused by sulphur dioxide emitted from the factories of Lake Region, Pittsburgh-Youngstown Industrial Region and New England Region and thus the forests have suffered great loss. Chlorine and nitrogen oxides emitted from the factories combine with the water and pollute the soils by altering the chemical composition. Huge quantities of particulate matters emitted from cement factories, lime kilns, coal mining, loading and unloading of coal, thermal power plants etc. reach the soils and thus pollute them by altering their chemical and physical properties.

Flakes and chips of mica from the mica mines spread over the soils and pollute them. Numerous mica chips may be seen strewn all over the agricultural fields in the vicinity of Kodarma mica belt of Jharkhand (India). Magnesite dusts, when mixed with soils, cause marked rise in the soil pH (increse in the soil alkalinity which causes salinization and decrease in potash (K), calcium (Ca), magnesium (Mg) and phosphourous to critical lower limit. Fallouts of metallic particulate matter from metal smelters into soils damage their physical and chemical properties. For example, the soils near copper smelters are so polluted that no plant growth becomes possible. The fallouts of mercury released from industrial processes and combustion of fossil fuels when mixed in the soils reach the food chain. Similarly, high concentration of lead pollutes the soils to large extent.

(4) **Chemical fertilizers and biocides** have now become essential part of modern mechanized agriculture. Excessive use of chemical fertilizers to boost agicultural production causes alteration in the physical and chemical properties of soils, though chemical fertilizers act as inorganic plant nutrients. The most dangerous pollutants are different kinds of biocides which destroy micro-organisms including useful bacteria and thus lower down the quality of soils significantly. In fact, rapid growth of population and commercialization of agriculture have been responsible for the phenomenal increase in the produciton and consumption of chemical fertilizers and biocides. According to an estimate the world consumption of biocides (pesticides, insecticides, herbicides etc.) has substantially increased from 25,030 billion tonnes in 1965-66 to 100,000 billion tonnes during 1980 which shows four fold increase within a period of 15 years. Biocides reach the food chains in toxic forms and ultimately enter the bodies of human beings and even animals through food they eat. It may be pointed out that biocides first kill germs and unwanted plants and then degrade the quality of soils and reach the plants through their roots. These toxic elements are ultimately transferred to human bodies and thus kill people through several fatal diseases. Biocides are, thus, called as **creeping deaths.**

The use of biocides has also gained momentum in India with the Green Revolution since 1960s. According to an estimate about 100,000 tonnes of biocides are used in India annually. According to the report of World Health Organization (WHO) about 500,000 persons become the casualties of biocides in one way or the other every year. The annual production of various biocides in India has increased from 2,350 tonnes in 1955 to 149,795 tonnes in 1983 thus registering more than 63 times increase in their production. The following types of biocides (pesticides, insecticides, herbicides etc.) are generally used to get rid off unwanted plants and to kill harmful insects and destroy pests to boost agricultural produciton.

(i) **Organic phosophate compounds** e.g. malathions. These are used to kill insects by damaging their nerve systems. Frequent use of these chemicals results in the accumulation of acetylchorine in the soils and ultimately these chemicals are transported to plant tissues. The mammals depending on these plants are thus adversely affected.

(ii) **Chlorinated hydrocarbons** e.g. D.D.T., dieldrin, aldrin etc. These insecticides are generally used to kill insects and micro-organisms. Chlorinated hydrocarbon compounds were developed as potent pesticides after World War II. The two general characteristics of these chemicals made them more popular in the beginning e.g. (i) These chemicals are toxic to a large number of plants and micro-organisms and insects and their use can control many pests and plant diseases and can destroy many unwanted plants simultaneously. (ii) These chemicals stay for relatively longer period in the soils and other components of physical environment and are not required to be used frequently. Besides, they were apparently less toxic to humans. It may be pointed out that these two fundamental characteristics of chlorinated hydrocarbon compounds are also dangerous to natural ecosystems and to humans as well.

D.D.T. proved to be boon to human society in the beginning because its use helped in killing a host of disease carrier insects such as mosquitoes and millions of people could be saved from typhoid, malaria etc. D.D.T. proved successful in eradicating malaria, incephalitis, dengu fever etc. D.D.T. was used world over to kill insects and germs upto 1971 without any suspicion but in 1972 its dangerous effects on humans and animals were brought to notice in the USA and hence its use was banned by the US government. It has been found out that D.D.T. may persist in soils for 20 to 25 years and thus reach the food chains through the plants.

(iii) **Arsenic containing pesticides** reach the soils and are transported to plants and thus to food grains. These chemicals cause gastric and digestive problem in humans.

(iv) **Sodium fluoroaccetates** are generally used to kill rodents and accumulate in the soils to reach the food chains.

The analysis of innumerable samples of food grains all over the world has shown that the human food is widely contaiminated by the concentration of pesticides, insecticides and herbicides and thus these synthetic chemicals have become a part of human diet all over the world. The main culprits are carbaryl, D.D.T., malathion, parathion, dieldrin, lindane, hepatachlor, aldrine etc.

Improper disposal of industrial and urban wastes and irrigation of agricultural fields from polluted urban sewage water near urban and industrial areas degrade the soil properties by changing their physical and chemical properties. The toxic chemical substances of industrial effluents and urban sewage enter the soils and pollute them mostly in the neighbourhood of cities and mills. The study conducted by V.K. Kumra in and around Kanpur city reveals the following facts : (i) Excessive use of chemical fertilizers and improper disposal of industrial wastes in the city boundary has caused rise in the alkalinity of the soils; (ii) Contamination of nitrogen varies from 40 pounds per acre to 640 pounds per acre; (iii) Phosphorous concentration in the soil ranges between 0.03 to 0.085 per cent; (iv) Soluble salts range between 0.03 to 0.27 per cent, and (v) Soil pH varies between 7.32 and 10.1.

Adverse Effects of Soil Pollution

Effects of soil pollution on human beings, animals and plants are far reaching. Since pollution degrades the quality of soils, soil pollution thus results in substantial decrease in agricultural production. Some forms of soil pollution even render the land unusable for crop farming. For example, soil erosion through rill and gully erosion converts the land into wasteland. Chemical pollutants in the form of chemical fertilizers and pesticides, isecticides and herbicides after reaching the soils reach the human and animal bodies through food chains and cause various diseases and several deaths. According to an estimate about 500,000 persons die every year in the world because of insecticides and pesticides. Most of the food grains in the USA, mainly wheat and corn, have become toxic due to these synthetic chemicals. Table 21.6 shows remains of D.D.T. in various food items in various states of India where chemical fertilizers and biocides are profusely used to boost agricultural production.

Table 21.6 : Traces of D.D.T. in different food items in India (mg/kg)

Food Items	Punjab	Haryana	Uttar Pradesh	Andhra Pradesh
Vegetables	0-1.11	0-1.52	-	0-10.0
Wheat	0-6.0	0.6-1.0	0.41-10	-
Pulses	0-102	-	10.0-175.0	0-8.0
Oilseeds	0-1.28	-	-	-
Milk	0.19-27.0	-	-	0-5.0
Butter	0.3-8.0	0.63-6.94	1.25-2.12	0.03-3.39
Ghee	2.57-11.0	-	2.72-13.0	2.10

Table 21.7 : Presence of D.D.T. in human fats in USA and India

Country	Year	Average daily Consumption of D.D.T. (in 000 tons)	Traces of D.D.T. in the fats of human bodies (mg/kg)
USA	1951-1970	25	7.0
India	1951-1965	10	27.0
India	1965-1974	10	20.0
India	1975-1978	13	12.0

Control of Soil Pollution

It is not only desirable but is also necessary to control soil pollution because the very existence of human beings and animals depends upon soils. It is very necessary not only to maintain but also to enhance the quality of soils because the supply of food for billions of world human population, fodder for animals and a host of raw materials come from soils. The following steps may be suggested to control soil pollution.

- to implement various control measures of soil erosion (see section 16.2 of chapter 16 of this book).
- controlled and judicious use of chemical fertilizers and pesticides, insecticides and herbicides.
- development of such pesticides and insecticides which do not harm human beings.
- immediate restriction on the use of D.D.T.
- proper disposal of industrial and urban wastes.
- use of urban and industrial effluents for irrigation purposes after proper treatment.
- proper land use and crop management.
- education to farmers about the proper uses of fertilizers and biocides.
- proper researches regarding the adverse effects of soil pollutants mainly toxic chemicals on various components of natural ecosystems.

21.8 SOLID WASTE POLLUTION

1. Meaning and Definition

Solid waste substances are those materials which become useless and hence waste after short period of thier use such as news papers, different types of cans, bottles, broken glass wares, plastic containers, polythene bags, ashes and domestic garbages. These discarded solid substances after their uses are variously called as **refuse, garbage, rubbish, solid waste etc.** These solid wastes require proper and ample space for their dumping and disposal. The envrionmental polution caused by these solid wastes is rapidly increasing in tune with rapid rate of industrial growth and urbanization. The problem of disposal of everincreasing quantities of solid substances has become a headache for not only industrialized and developed countries but also for most of the developing countries. For example, the city of New York (USA)alone produces 2500 truck load of waste solid substances such as beer and coke cans, milk bottles, other types of bottles, papers, plastic goods, containers, polythene bags, domestic garbages etc. measuring about 25,000 tons every day. There are numerous graveyards of abandoned automobiles in the developed countries.

2. Sources of Solid Wastes

Sources of solid waste substances may be grouped into the following two categories :

(1) Production centers, and

(2) Consumption centers.

Production centres may be further divided into small-scale production centres and large-scale or industrial produciton centres. Consumption centres contributing solid waste substances may be further divided into individual house, community centres, markets and municipal garbage centres. Alternatively, sources of solid waste substances may be grouped into two broad categories as follows :

(1) Household/domestic sector, and

(2) Industrial/commercial/urban sectors.

Most of solid waste substances are not biodegradable such as plastics and polythenes.

It may be pointed out that there is direct positive relationship between the amount of solid wastes produced and the affluence/richness of the economically rich and industrially developed western countries as their **use and throwaway culture** has been responsible for the acute problem of solid waste pollution because all of the substances are thrown away after use. None of the used items is reused or recycled. On the other hand, economically poor societies of the developing countries produces much smaller quanties of solid waste substances than the economically rich societies of the western developed world because they use these items several times but now developing coutnries are also adopting **'use and throw away culture'** atleast in urban areas. The plastics and polythenes have become nuisance in most of Indian cities. For example, packagings are such that they are used many times; bottles used for solft drinks and milk are used again and again; broken bottles and cans are remelted and thus new bottles and other glass items are made again and again. Not only this, used bottles of milk and soft drink are used for refilling till they are damaged. Many waste substances are again used in a number of ways. For example, news papers are sold back by the subscribers to junk collectors. These used news papers are then put to various uses such as for packing bags, manufacturing of hard board etc.

3. Types of Solid Waste Substances

Solid waste pollutants are divided into several types based on their sources as follows :

- mining wastes,
- agricultural wastes,
- industrial wastes,
- municipal wastes,
- packing wastes,
- human wastes,
- animal wastes,
- radioactive and nuclear wastes

(1) Mining wastes : are produced during mining operations wherein huge quantities of wastes are dumped on land surface which may be otherwise useful for other purposes. For example, for the mining of metallic ores, huge quantities of earthen materials, rocks and other wastes are created. Similarly, for coal mining surficial crustal materials are removed to expose coal seams. The removed materials are heaped at other places. Thus mountains of waste mining materials are created which not only occupy valuable land surface but also create nuisance, because mine wastes contain, some times, toxic chemicals which pollute the nearby environment. Limestone quarrying produces immense volume of useless debris.

(2) Industrial wastes : include huge amount of abandoned items which create several environmental problems. For example, huge quantities of bagasse are produced in sugar mills during the proces of sugar production. These bagasses are heaped in the vicinity of sugar mills. Thus the sugar mill overburden of bagasses after rotting stinks and spreads unbearable foul smell. Copper smelters and aluminium industry produce dangerous waste substances which are very much injurious to vegetation and soils. Many more examples may be cited.

(3) **Agricultural wastes** : include roots and stems of crops, straw, hay, dung, food articles etc. There is almost no problem of agricultural waste subtances in developing countries becasue these items are used and reused in a number of ways. For example, dungs are used for compost and manures, for domestic fuels etc,; straws are used as animal feed; paddy plants after harvesting and separation of grains are either used as fooder or are burnt in the farms for manures. But the problem of disposal of these agricultural wastes has become headache in the developed countries. The USA produces about 18 million tons of agricultural wastes ever yeary. The increasing use of harvestors in India for 'rabi' (wheat) and 'kharif' (rice) crops now produces huge quantities of abandoned plants of wheat and paddy.

(4) **Municipal wastes** : inlude solid wastes such as papers, plastics, metal cans, glass bottles, plastic bottles and cans, aluminimum foils, metal junks, polythene bags, garbages mostly coming from domestic uses etc. It may be further pointed out that most of these items are reused and recycled in poor countries and therefore the problem of solid waste pollution is not so acute at least at present as it is in the developed countries. For example, news papers, after use, are reused in a number of ways but these are thrown out in the developed countries. It may be mentioned that one day issue of New York Times news paper (for Sunday issue) requires huge quantities of news print which come from 75,000 trees. The disposal of waste news papers poses an acute problem in the developed countries. For example, municipal wastes in the USA amount to 175 million tonnes per annum wherein daily output of municipal wastes is upto the tune of 480,000 tonnes. The city of New York alone produces 2500 truck-loads of municipal wastes daily (like cans, bottles, plastics, paper and other garbages coming out from domestic uses) wich amount to 25,000 tonnes of waste substances per day. London produces about 8000 tonnes of garbage a day (all data upto 1991).

About 45 Indian cities having the population of more than 300,000 generate about 50,000 tonnes of municipal wastes per day (1991 data). Four big metropolitan cities viz. Greater Mumbai, KolKata, Delhi and Chennai produce huge quantites of municipal wastes in Indian context but these are still much smaller than metropolitan cities of the developed countries. Kolkata Metropolitan District (CMD) generates daily garbage of 2500 tonnes which is only one tenth of the garbage produced by the city of New York. It has been estimated that the annual municipal wastes of Kolkata may rise to 912,000 tonnes in the immediate future or 7,600 tonnes per day. About 70 per cent of the municipal wastes of Kolkata Metropolitan District is disposed off by the municipal authorities but the remaining 30 per cent creates severe environment problem. Daily outcome of municipal wastes from Greater Mumbai is about 3,000 tonnes. About 16,000 persons and 270 carriers are employed to collect the garbages and to dispose them off at suitable dump sites. According to the Information, Mumbai Metropolitan Development Authority (1984) 3 major dump sites viz. (i) municipal depressed land of Deonar, (ii) three dumping sites in the suburbs of Malad, Bomby and Muland, and (iii) Dhanwari Mohan Creek accommodate 25 per cent, and 50 per cent of municipal garbage respectively. Delhi and Chennai produce municipal wastes of 2000 tonnes and 1200 tonnes daily respectively.

The municipal garbages of Indian cities generally comprise carbon and organic matter, compostable matter, ash, earth, moisture, stone, coal, straw, leaves, vegetables, paper, rags, cans, bottles, plastics, polythene bags etc. The municipal waste substances are also classified into (i) non combustible wastes, (ii) highly combustible trash, (iii) combustible wastes, (iv) animal and vegetable trash etc.

(5) **Packing wastes** : include packagings of different materials such as polythene, plastics, paper board, paper, jute, flax (gunny bags) etc. These packagings are generally used several times in different forms in developing countries but these are immediately discarded after their first use and hence present the problem of their disposal.

(6) **Human wastes** : include fecal matter in the cities which is disposed off in several disposal bodies such as udnerground pits, lakes, tanks, rivers and seas. In the rural areas mainly in the developing countries people use open lands as lavatories and thus stools pose a serious environmental problem. These human excreta are washed by rainwater and are carried to nearby lakes and streams. **Animal wastes** such as dungs, their skeletons and waste substances from slaughter houses pose serious disposal problems. In India dungs are picked up by farmers and are used as manures and cooking fuels. Similarly, bones of dead animals are used in fertilizers industry.

4. Management of Solid Wastes

The integrated management plan of solid wastes includs the following steps :

(1) Collection of solid wastes,

(2) Disposal of solid wastes, and

(3) Incineration of combustible wastes.

The management of solid wastes includes, as referred to above, collection of waste substances, their classification, and their disposal in suitable dumping sites and incineration of combustible substances. There are quick and efficient automatic machines for collection and disposal of solid waste sbstances in the developed countries but rapidly increasing quantities of solid wastes are dangerous signs of environmental problems in near future. The dump sites in the western world are generally lakes, underground pits and sea water. Disposal of solid wastes from various sources has created ecological problem in the littoral areas because of deaths of marine organisms including fishes and corals.

There is no proper arrangement for the collection and disposal of domestic wastes and sewage in the rural areas of India and hence these substances spread on the ground within the village and outside the village. The collection and disposal of solid wastes and domestic sewage is yet another serious problem in the small towns of the country. Dumps of domestic garbages remain at their places for several days and thus pollute the environment by foul smell and releasing harmful gases.

(1) **Collection** : of municipal wastes is the first step in the management of solid waste pollution. In Indian cities and towns domestic solid waste substances are generally thrown by the residents in specially enclosed masonry structures on road sides, on the roads, in the corners of the buildings, behind the boundary walls etc. Even the residents of flats in multi-storeyed buildings throw their domestic wastes downward which come as 'missile' on the ground while dusts and ashes spread in the air. These heaps of municipal garbages are further spread by stray cattle, pigs, rats, rodents and poor people who collect some reusble items such as iron and aluminium junks, paper, plastics etc. These heaps of solid wastes are then collected by municipal personnel and are carried by trucks and lorries to dump sites. The collection and clearance of municipal wastes from various collection sites in the cities are seldom performed regularly in most of the Indian cities. It is thus desired that the frequency of waste collection should be increased and properly maintained. The solid wastes should be collected by municipal personnel at least twice a day from the market and business areas mainly from fruit and vegetable markets and at least once a day from residential localities. The same norm should be applied for the clearance of domestic wastes in the small towns also.

(2) **Disposal** : The second step of the management of solid waste pollution is the proper and scientific method of disposal of solid wastes. Garbage (including all types of solid wastes) disposal involes the following three steps :

(i) sorting (classification) of waste substances,

(ii) dumping of non-combustible substances into suitable dump sites, and

(iii) incineration of combustible substances.

The solid wastes are separated into the following categories of waste substances :

- combustible organic matter,
- non-combustible solid wastes,
- highly combustible wastes, e.g. papers, card boards, plastics, rubber items etc.
- combustible wastes, e.g. wood, scrap, cartoons, floor sweepings etc., and
- animal and vegetable wastes and reusable wastes.

(i) **Composting : Compostable** organic substances such as vegetables, plant leaves, animal and human wastes etc. (which are biologically degradable-biodegradable substances) should be composted either through open window composting method or through mechanical composting method and thus useful manures can be produced.

'**Composting** may solve twin problems of India, i.e., proper disposal of solid wastes, and production of organic manure for increasing agricultural output. According to an estimate, a town with one lakh (100,000) population may produce 20,000 tonnes of garbage and 8,000 tonnes of night soils which can be converted into 18,000 tonnes of compost (organic manure) per year' (J. Singh and D.N. Singh, 1988).

(ii) **Dumping : Non-combustible** solid wastes such as metals are dumped and compacted in garbage disposal sites such as landfills, depressed ground or even in open wasteland.

(iii) **Incineration** : Combustible substances may be burnt in specifically designed incinerators such as **'multiple hearth furnaces'** (MHF) and **'fluidized bed furneces'** (FBF).

Pyrolysis is another way of treatment of solid wastes wherein wastes are broken down through the process of destructive distillation in an oxygen free atmosphere into gases like carbon dioxide (CO_2), CO (carbon monoxide), H_2, C_2H_2, C_2H_4, and CH_4 and into liquids like tar, light oil, water soluble distillate and solid char. Thus burning of solid wastes may solve the problem of their disposal as well as may yield energy for various uses.

21.8 NOISE POLLUTION

1. Meaning and Definition

Noise pollution may be defined as the state of discomfort and restlessness caused to humans by unwanted high intensity sound known as noise. The noise is the main pollutant of noise pollution which may be both natural and artificial. Natural noise polluton results from natural sources such as cloud thunder, high intensity rainfall, hailstorms, water falls etc. It may be widespread, sporadic, frequent or rare.

On the other hand, artificial noise pollution is caused by high intensity sound created by human activities and therefore artificial or simply called as noise pollution is increasing in both dimension and intensity with increasing urbanization and industrialization. It is apparent that the main source of noise pollution is sound which may be caused naturally or artificially. It may be pointed out that unlike other pollutants, sound/noise is not an element, compound or substance and thus it cannot accumulate and harm future generations. There is no lag-time between its generation and impact on human beings and of course on animals. In other words, noise has instantaneous effects on nearby orgaisms. Unlike other pollutants, it cannot be carried far away and spread from its source area.

2. Sound and Noise

Sound is a special type of pressure wave which is usually transmitted through air (also through solids and liquids but with very low intensity) and is received by the receiving mechanism, the hearing apparatus (ear). In other words, 'sound, the form of energy giving the sensation of hearing, is produced by longitudinal mechanical waves in matter including solid, liquid and gas and transmitted by oscillation of atoms and molecules of matter. The intensity of sound waves, measured in watts per square metre (w/m^2), is the flow of energy per unit time ($second^{-1}$) through a unit area to the area perpendicular to the direction of propagation of waves' (K.P. Singh and S. Sinha, 1983).

The speed of sound waves depends upon the density and elasticity of the transmitting medium such as gas (air), liquid and solids. The pressure waves or sound waves after being generated in the air at sound source are transmitted through air in all directions in spherical manner. The intensity of sound waves decreases with increasing distance from the source of sound. There are certain characteristics of sound waves which must be taken into account before studying various aspects of noise pollution as follows :

- ➤ The intensity of sound waves decreases as the distance increases from the source of sound.
- ➤ After being hit by solid objects sound wave is reflected.
- ➤ Two sound waves, after being reflected by solid objects, are sctterecl or dispersed.
- ➤ Sound waves are also absorbed by perforated objects.

High pressure sound or high intensity sound termed as 'unwanted sound' is called **noise** which causes discomfort to human beings and interferes with their efficiency. In oter words, noise is defined as unwanted high intensity sound without agreeable musical quality. In fact, noise is that higher level of sound which becomes unpleasant, and causes discomfort and fatigue to human bodies by damaging hearing ability, brain and balancing mechanism. It may be pointed out that differentiation between sound and noise is a subjective matter as the concept and perception of sound and noise varies from person to person. For example, high intensity disco and pop music is very much pleasant to those people who are fond of such music but it is nuisance and unwanted sound to most of people.

Inspite of subjectivity of noise some objective criteria for the subjective human reactions to noise have been identified such as annoyance, interference with speech, damage to hearing, decrease in work performance, deficiency etc.

3. Measurement of Noise Level

The common measurement unit of sound in acoustics, the science of sound, is the decibel (dB) which is the unit of the measurement of the intensity of sound. The other unit of the measurement of sound pressure is **weighted sound pressure** (SPL) or very commonly known as dB (A) in abbreviated form. The fundamental difference between these two noise level measurements is that dB is the measure of sound intensity while dB (A) is the measure of sound pressure but dB(A) scale is more commonly used because it is quite easier to construct instruments to measure the pressure of sound wave rather the intensity of sound waves.

The decibel (dB) scale begins with 0 which represents the faintiest sound being audible to a normal human ear. It is to be remembered that 'in the decibel scale each ten fold increase is represented by 10 dB'. For example, 0 is the threshold value for the faintiest sound, if the sound intensity increases 10 times more than the faintiest sound, the intensity on decibel scale will be 10 dB; if the sound intensity increses 100 times, it will be 20dB; 1000 times increase = 30 dB, 10,000 times increase = 40 dB, 100,0000 times increase = 50 dB, 1000,000 times increase = 60 dB, 10,000,000 = times increase = 70 dB, 100,000,000 times increase = 80 dB, 1,000,000,000 times increse = 90 dB, 1,000,000,000,000,,000 times increase = 150 dB, 100,000,000,000,000,000,000 times increase = 200 dB and so on.

Sound Intensity Factor 1 (SIF) measuring 0 dB on decibel scale represents the faintiest audible sound. 10 dB denotes normal breathing and rustling of leaves; whispering range of sound is denoted by 20 dB; 50-55 decibels may delay or interfere with sleep; 60 dB represents the level of normal talk; 90-95 dB causes irreversible changes in the nervous system of human bodies and 150-160 dB may prove fatal to several animals. Table 21.8 presents noise levels for various sounds.

Table 21. 8 : Noise level

Sound sources and types of sounds	Decibels dB)	Sound Intensity Factor (SIF)
1. Threshold of hearing (faintiest audible sound)	0	1
2. Normal breathing and rustling of tree leaves	10	10
3. Sounds of very quiet place	20	100
4. Whispering e.g. libray	30	1000
5. Sounds of average living room or quiet office	40	10,000
6. Noise of quiet restaurant and light traffic nosie	50	100,000
7. Noise during normal conversation	60	1,000,000
8. Noise of automobiles (cars, motor cycles, trucks, house hold machines-mixer, grinder, food blender etc.)	70-80	10,000,000-100,000,000
9. Noise of water falls at base (noisy waterfalls such as Niagra falls)	90	1,000,000,000
10. Heavy automobile traffic, jet aircrafts upto 300 m height	100-110	10,000,000,C00 to 100,000,000,000
11. Jet aircrafts at take off point	150	1,000,000,000,000,000
12. Rocket engine	180 to 195	1,000,000,000,000,000,000

4. Sources of Noise Pollution

On an average the sources of noise pollution are divided into the following 3 categories :

(1) **natural sources :**

e.g. cloud thunder; high velocity wind such as hurricanes, tornado, gales, thunderstorms, high intensity rainfall; hailstorms; waterfalls; surf currents etc.

(2) **biological sources :**

examples : sounds of varying intensities of wild and tame animals such as roars of lions in zoos, street dogs, jackals in the neighbourhood of villages and fringes of urban areas, human sounds such as during laughing, crying, shouting, singing, quarreling etc.

(3) **artificial sources :**

examples : noise created by man through his activities and recreations such as musical instruments, automobiles, aircrafts (at the time of take off), factories etc.

Soures of noise are also classified on the basis of areas of origin of sounds and noise into 3 categories as follows :

- rural sources of noise pollution
- urban sources of noise pollution, and
- industial sources of noise pollution.

(1) **Rural sources** generate least noise pollution because of general absence of ingredients of industrial and urban areas. There are certain occasions when the level of pollution becomes higher than normal permissible level (25-35 dB) e.g. during festivals (Holi, Diwali, Moharram etc.), religious rituals (marriages), mourning, elections, quarrels, fairs, etc. Street dogs are perpetual sources of high level of noise pollution. Very often barking dogs disturb the sleep of villagers during night. Diesel engines used for pumping sets and flour mills cause high level noise pollution.

(2) **Urban source** of noise polluton includes noise produced from (i) automobiles (motor cylces and scooters, tempo, cars, lorries and buses, trucks, trains) and aircrafts, (ii) rockets, (iii) defense experiments, rifle shooting, mortar firing, other firing explosions, (iv) hawkers, (v) vegetable and fruit markets, (iv) children playing, (vii) electioneering, (viii) religious propaganda, (ix) cultural programmes, (x) musical nights, (xi) festivals, (xii) worships (prayers in temples and mosques), non-stop ricitation of Rama Charita Manas, Geeta, Upanishads etc., (xiii) advertisements, (xiv) mourning at the time of deaths etc. Loudspeakers are the most significant noise pollutants as these are used at large-scale during all types of festivals and religious fairs of all communities, national festivals like independence day (15th August) and republic day (26th Janururay), electioneering, advertisement, political and religious propaganada, worships, bhajan and kirtan; speeches etc.

(3) **Industrial source** of noise pollution includes noise produced from factories and all other sources of noise pollution in urban areas such as noise created from automobiles, loudspeakers, defense establishment, markets, religious and cultural gatherings etc. Industrial sources of noise pollution also include noise caused by mining operations such as operations of bulldozers, trucks, and machines, blasting of rocks by dynamites, operation of drillers etc.

5. Types of Noise Pollution

Noise pollution may be classified in a number of ways on different criteria as follows :

(A) On the basis of areal source
  (1) rural noise pollution,
  (2) urban noise pollution,
  (3) industrial noise pollution, and
  (4) mining noise pollution.
(B) On the basis of sources of noise
  (1) natural noise pollution caused by noise created from natural sources as referred to above,
  (2) biological noise pollution, and
  (3) man-made noise pollution.
(C) On the basis of periodicity
  (1) pollution caused by intermittent or non-uniform noise,
  (2) pollution caused by continuous or uniform noise,
  (3) pollution caused by instantaneous or impulsive noise such as explosions, gun shots, thunder etc.

The noise pollutions caused by intermittent and continuous noise are most injurious to human beings becuse they are quite annoying, disturbing and fatiguing as they cause much discomfort to human health and mind. These pollutions are generally caused by the noise created from entertainment establishments (cinema halls, dance halls, etc.), public addresses by politicians, religious addresses, hospitals, schools, common vegetable-fruit and fish markets, vacuum cleaner, television and radio sets, sewing machines, stereomusic players, grinder, mixer, fans etc. Sonic booms created by supersonic jet aircrafts, high intensity sound waves caused by the explosion of high power bombs, blasting of rocks by high power dynamites etc. create such powerful sound waves that even window glass panes are rattled. In fact, sonic boom is the noise which is caused by the objects travelling faster the speed of sound and is produced instantaneously. Sonic boom is expressed in Mach Unit. For example, the sound produced by the objects travelling at the same speed of sound is termed Mach 1, while the sound created by the object travelling at the speed twice to that of sound is termed Mach 2 and so on.

6. Noise Pollution in India

Most of the million cities of India are suffering from noise pollution because of phenomental growth in automobiles and other noise pollutants consequent upon unchecked growth of urban population. Loudspeakers and traffic noise are the biggest nuisance in Indian cities. Every nook and corner of a city is echoed by blistering and deafening noise created by overcrowded loudspeakers tuned at full volume during festivals of all communities, cultural programmes, public addresses, national festivals, Indian victories in games and sports in international encounters etc. Most of the big cities of India have high level of noise pollution, generally above 70 dB e.g. Delhi (89 dB), Kolkata (87 dB), Mumbai (85 dB), Chennai (89 dB), Cochin (80 dB), Madurai (75 dB), Nagpur (75 dB), Trivandrum (70 dB) etc.

Table 21.9 : Acceptable noise levels in different areas.

Location	Noise levels (dB)	Location	Noise levels (dB)
Rural areas	25-35	Radio and TV Studios	25-35
Suburban areas	30-40	Music roon	30-35
Residential (urban)	35-40	Hospitals, class rooms, hotels, conference rooms etc.	35-40
Residential and business (urban)	40-45	Court rooms, private offices, libraries	40-45
City areas	45-55	Large public offices, banks, storages, restaurants etc.	50-55
Industrial areas	50-60		

Source : I.S.T. Publicaton UDC 534 : 83 : 7144, March 1969.

7. Effects of Noise Pollution

Noise pollution or say exposure of human beings to noise levels higher than recommended level causes a number of adverse effects ranging from mild annoyance to permanent hearing loss. The effects of noise pollution of humans are generally of four types as follows :

(1) General effects,

(2) auditory effects,

(3) psychological effects, and

(4) physiological effects.

(1) General effects of noise pollution : caused on humans include speech interference, annoyance, sleep interference and related after - effects and problems. Speech interference is generally caused by community noise. Speech interference simply means non-audibility of speech to a particular person due to loud community noise. In other words, in loud community noise such as in vegetable-fruit-fish markets, fairs etc. a person may hear only a few or even none of the speech sounds necessary for satisfactory intelligibility. Sleep, which is very much necessary for the good health of human beings, is not only disturbed by high noise level but its duration is also shortened. There is a negative relationship between noise intensity and sleep duration e.g. as the intensity of noise increses, the duration of sleep decreases. Frequent high noise disturbs the sleep and awakens the person which causes many socio-economic problems. For example, people living in the villages along the main rail routes are awakened several times during night due to high level noise produced by passing trains and hence produce more children. Sounds of all types cause annoyance and irritation in most of the people. The annoyance caused by high intensity sound some times causes mental imbalances.

(2) **Auditory effects** : include the damages done to hearing mechanism in humans due to various types of noises. Noise pollution causes hearing damages in a number of ways. 'The problem has been thrown with sharp focus by the discovery that some teen-agers were suffering from permanent hearing loss following long exposures to amplified rock music and by public concern about the effects of sonic booms that would be caused by supersonic transports (SST) if they were put into commercial service' (P.R. Ehrlich and A.H. Ehrlich, 1970). Auditory effects may be divided into two categories viz. (i) temporary and mild damage to hearing mechanism, and (ii) permanent hearing loss. It has been found that even short exposures to high intensity noise may damage and rupture the ear drum and may cause temporary deafness. Experiments have revealed that noise in excess of 90 dB may produce varying degrees of impairment of hearing depending upon the length of exposure, frequency of sound waves susceptibility of the individual against noise.

It has been shown that a person subjected to exposure of 2000 cycles frequency of noise levels of 80 dB may lose his hearing ability by 15 dB in ten years. Long and continuous exposure to high intensity sound leads to permanent loss of hearing rendering a person deaf. An intensive study to measure the Noise Induced Hearing Loss (NIHL) among the factory workers in the textile, automobile, fertilizer and chemical industries in the cities of Chennai, Coimbatore, Madurai, Cochin and Trivandrum revealed the fact that one out of every four factory workers suffered from incurable NIHL and 10 per cent of the people such as traffic constables and pavement vendors in three cities suffered from NIHL due to their exposure to traffic noise. Community noise caused NIHL among 3 per cent of the people of these cities.

According to a survey of students between the age group of 5-10 years in the industrial areas, railway colonies and in other areas of high noise about 60 per cent of the students could not concentrate in their classes because of high level noises produced by loudspeakers and running trains.

(3) **Psychological effect** : High level noise causes many behavioural changes among humans as well as animals. Unwanted noise very often causes annoyance, irritation, and fatigue which result into low performance, low efficiency and frequent errors. Further, high frequency of high level noise and exposure of human being for long period to such high level noise may cause tension in muscles, nervous irritability and strain and neurotic mental disorder.

(4) **Physiological effects** : Annoyance, irritation, anxiety, strains and stresses caused by noise pollution may cause changes in harmone content of blood which in turn may introduce changes in human bodies. Noise pollution of various sorts caused by varying levels of noise may cause high blood pressure, heart diseases, dialation of pupils of the eyes, tensing of the voluntary and involuntary muscles, diminution of gastric secretion, neuromuscular tension, nervousness, stomach and intestinal diseases such as ulcer etc. Sudden very high level noise caused by sonic booms or explosions may lead to termination of pregnancy in early stages. Many cases of congenital defects in newly born babies have been reported in the areas which are generally close to high noise regions.

7. Control Measures of Noise Pollution

The problem of noise pollution can be approached and tackled in a number of ways viz. (A) Since there are three components of noise pollution e.g. (i) source of noise, (ii) medium of noise, and (iii) objects affected by noise, and hence noise pollution should be tackled at any of the three components. Since noise pollution involves individual and communities, it should also be tackled at individual, community and governmental levels. Further, noise pollution abatement programmes include two aspects viz. (i) noise reduction, which may be achieved through several techniques, and (ii) noise control.

Noise Reduction : Intensity of noise may be reduced by several devices e.g. enclosure of machinery with sound absorbing materials which can reduce the intensity of noise produced from industrial operations. The following materials are recommended for effective reduction of noise.

Materials	Noise Reduction
Cinder block, 10 cm thick	25 dB
Glass, 5/8 cm thick	50 dB
Cinder block, 10 cm thick, plastered on one side	42 dB
Cinder block, 10 cm thick, plastered on both sides; brick 10 cm thick	45 dB
Two cinder blocks, 7.5 cm thick separated by equal amount of air, with plaster on both outside surfaces	55 dB

It may be pointed out that the reduction of noise by various techniques involves money and thus the process is costly and may not be adopted by factory owners.

Thus, the most effective way of controlling noise pollution is to control noise at source points and at receiving points. Noise may be controlled at source by providing silencers to the machines, by reducing the amplitude of existing forces, by proper greasing of vital parts of machines to reduce friction etc. Noise generated by record players and loudspeakers may be effectively reduced by convincing the people and by effective prohibitory laws. Noise pollution may also be reduced by controlling the transmission paths of sound waves through a variety of measures e.g. (a) by increasing the distance between the source and receiver of noise, (b) by proper layout of buildings, (c) by deflecting the path of sound waves etc. The intensity of noise at receiver's end may be effectively reduced by providing acoustic (sound) absorbing materials in the community halls, dance halls, cinema halls, temples, churches, mosques and other buildings affected by high intensity noise. The effects of noise pollution may also be minimized at the receiver end at individual level by using ear plugs, ear muffs or noise halmets or small booth in the machine room. Road side plantation has proved to be effective measure of control of noise pollution as green trees reduce the intensity of noise by 10 to 15 dB. Traffic rules particularly about the silencers in the automobiles plying in the cities must be strictly enforced. Railroads and highways should be routed away from the cities via by-passes and the cities should be linked to the main roads by link and connecting roads.

22

ENVIRONMENTAL RESOURCES

The resources in the form of matter and energy are of vital significance for the successful survival of all types of life on the planet earth in general and for human beings in particular. In fact, all aspects of human society, such as social, cultural, economic and political, depend on resources. Therefore, meaning, classification, assessment and evaluation, uses and abuses, conservation and management of all sorts of resources are very significant aspects of environmental geography. The very fundamental principle of resources is that resources, even renewable, are finite and hence this principle should always be kept in mind while exploiting and utilizing resources.

Environmental resources simply mean natural resources including both biotic and abiotic resources.

22.1. IMPORTANCE OF RESOURCES

The resources are fundamental base for the economic growth and development of human society but their withdrawal from the nature, mode of their uses by human being and their disposal have enormous adverse effect on the environment. It is, thus, imperative to study the linkages between resource use and the environment so that proper management of resources, both effective resources and resources out of place (waste materials after use) and remedial measures of environmental pollution and degradation arising out of resource use and disposal of waste materials may be made possible.

A few aspects of resources are of most concern to the present society and for future generations as follows :

(1) Majority of the raw materials of the industries mainly metals have formed and accumulated over long period of time (millions of years) through exceedingly slow geological processes but they are being consumed at present at an alarming rate. This may result in low supply of certain key minerals or even in complete depletion. Thus arises the question of adequacy and inadequacy of certain key minerals which the present society must take note of.

(2) All types of environmental/natural resources are finite and have accumulated over a long period of time. These resources are being used at a very fast rate and there is every likelihood that we will run out of these resources within a few hundred years or even less. These resources are used for the supply of most of energy in the industrial, transport and domestic sectors. The combustion of mineral oils, natural gas and coal pollute the atmosphere.

The very composition of the atmosphere in terms of natural gaseous composition is altered and modified which consequently affects the atmospheric processes. For example, emission of carbon dioxide through 'human volcanoes' (chimneys of factories) increases the concentration of CO_2 in the atmosphere which in turn increases the green house effect of the atmosphere resulting into rise of temperature at the earth's surface and consequent changes in the radiation or heat balance of the earth. The use of petroleum in the operation of motor cars, trucks, rail engines and air crafts releases nitrogen oxides into the atmosphere which may deplete the ozone which is very vital for all types of life on the earth because depletion in ozone may allow ultraviolet solar rays to reach the earth's surface. This may result in the rise of temperature and thus alteration of terrestrial heat balance. The release of sulphur dioxide (SO_2) into the air by combustion of fossil fuels causes acid rains.

(3) Withdrawal and use of minerals has immense impact upon the environment. For example, extraction of minerals creates pits and scars on the earth's surface and this leads to destruction of biotic community. Withdrawal of groundwater results in the formation of large cavities beneath the earth's surface which ultimately cause surface collapse and subsidence. Certain industrial minerals, such as metals, become wastes after their uses. The disposal of such waste materials into water and soil pollutes them and in few cases the resultant pollution becomes hazardous to human society and other organisms of biospheric ecosystem.

The second type of industrial resources includes fossil fuels such as mineral oil, natural gas and coal. These resources are also finite and have accumulated over a long period of time.

(4) Environmental/natural resources belong to all biota including both plants and animals communities in general and human community in particular, so all biota have natural right for rational use of natural resources for their survival. No one is authorized to misuse environmental/natural resources. There should be rational exploitation and optimum utilization of resources so as to maintain sustainable environment, sustainable development and sustainable society.

(5) The introduction of new substances into natural ecosystems creates serious environmental problems. It may be mentioned that new substances, which were not present previously in the natural environment, are continuously being introduced into the air, water and soils.

Such new substances, the result of modern industries, pollute the air, water and soils sometimes to such an extent that they become unusable. The most dangerous one is radioactive substance spewed into the atmosphere by nuclear explosions. These dangerous radioactive substances fall on the earth's surface under the impact of precipitation and enter the soils and thereafter they are circulated into the plants through root osmosis and are further circulated into food chains and food webs via different trophic levels and thus become lethal to all of the organisms in general and human beings in particular. Besides, radioactive substances also adversely affect the organisms including man and cause deaths, impairment of limbs, several types of diseases and physiological disorders of severe magnitude. The catastrophe of nuclear disaster at Chernobyl in Ukraine during 1988 is a burning example of adverse environmental effects of use of minerals like uranium, thorium etc. through most advanced and sophisticated technology. The production and rise of several synthetic compounds such as insecticides and herbicides are other examples of new substances coming out of industrial production, which are used for agricultural purpose but these enter the surface water and soils and ultimately affect the food chains and organisms.

(6) Mishandling of resources and negligence of the upkeep of the resources also affect the environment adversely. For example, leakage of petroleum from huge ships and oil tankers into sea water causes oil slicks which rapidly spread over water and become disaster to marine life directly and the human beings depending upon marine resources indirectly. The leakage of 100,000 tons of crude oil from the crashed huge oil tanker near La Coruna off the Spainish Coast in 1976, the leakage of immense quantity of crude oil off the Alaskan coast (1989) and the leakage of killer gas from the Union Carbide Factory at Bhopal (India) in 1984 are a few examples

of many such incidents which tell the impact of negligence and failure of technology on the environment. The list of adverse effects of exploitation, uses and misuses of resources on the environment is very large one and it is very difficult to accommodate all of them in the present format of this book.

22.2 RESOURCES : MEANING AND CONCEPT

The term resource is a dynamic one because its meaning changes with the advancement of knowledge, society and technology. Any thing or substance which is useful to mankind is a resource. In other words, a resource is some thing which is used by man to satisfy his needs and aspirations. The concept and meaning of resources changes with cultural and technological changes. For example, now thoughts, ideas, beauty, intelligence etc. have also become resources. We are concerned here with only natural resources or environmental resources.

According to R.F. Dasmann (1968) in the beginning 'natural resources were those materials which were of value to a particular human culture. Today, everything on earth is useful or of value to man and consequently a natural resource'. Norton Ginsburg (1957) has defined natural resources as 'all the freely given activities plus the additional non-material quality of situation or location'. According to E.W. Zimmermann the word resource does not refer to a thing nor a substance but to a function which a thing or a substance may perform to an operation in which it may take part. Natural resources in themselves are not resources as they are inert unless they are used by human beings. Thus it is apparent that resources have functional relationship between man's abilities to exploit substances and natural environment or natural ecosystem. 'That is why resources are not fixed but dynamic and derive their meaning and purpose through increasing knowledge, expanding technology and social needs and objectives. Their development depends upon their cultural appraisal which is determined by perceptions, attitudes and wants on one hand and technological innovations, financial and institutional capabilities on the other hand' (L.R. Singh, et al., 1983).

J.D. Chapman (1969) has defined three basic terms which are very often used in Resource Science and Resource Management as follows :

(1) Resource Base

Resource base refers to total stock or the sum total of all components of environment that would become resources as such if they could be extracted from the environment.

(2) Resource

Resource means the proportion of resource base that man can make available under given social and economic circumstances, within limits set by technological advancement.

(3) Reserves

Reserves refer to the proportion of resource base that is known (with reasonable certainty) to be available under prevailing social, economic and technological conditions.

Ecologically, the resources,. say natural or environmental resources may be defined as follows :

'The environmental or natural resources are the sum total and outcome of the basic ecological variables such as energy (solar, geothermal and chemical energy), matter (both biotic and abiotic), space (in terms of earth's surface, both land and aquatic space), time (in terms of ecological changes through time), and diversity (of biotic-biodiversity, and abiotic variations in both space and time).

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22.3 PERCEPTION OF RESOURCE AVAILABILITY

Perception of resource availability largely determines the nature and amount of exploitation and utilization of natural resources. Perception of the availability of resources has changed through various stages of human history and with the advancement of knowledge about the earth and its resources. L. Zobler (1962) has identified three major periods of changing perception of resource availability since 1850 as given below :

(1) **1850-1925** : An era of wasteful use of resources because of the general public belief that the natural resources were abundant as 'nature was limitless storehouse of raw material resources'. This belief or say perception of resource availability led to unchecked but wasteful exploitation of natural resources without having any care for their conservation upto 1900. It was only the first two decades of the 20th century that some attention was paid towards the conservation of natural resources.

(2) **1925-1950** : A transition period of rapidly increasing demands for raw material resources due to widespread erosion of soils by wind and water; flood damage; more resource use during second World War; more resource use during post-war period to reconstruct the damages done by the war; rapid increase in the world population; rising per capita standard of living; political fragmentation (e.g. division of Germany into West and East Germanies, Korea into North and South Koreas etc.); emphasis on self sufficiency in raw materials.

(3) **1950-1960** : A period of relative shortage of resources (because of rapid rate of industrial growth and urban expansion and of course due to increasing consciousness about the endangering of environment due to unchecked use of natural resources).

(4) **Post-1960** : T. O' Riorden (1971) has added a fourth phase of the perception, utilization and availability of natural resources as **post-1960 period** which is charaterized by growing concern for environmental crisis and ecological disaster caused by reckless and rapacious exploitation of natural resources without caring for ecological balance and stability of natural ecosystem. Thus growing concern of environmental collapse and crisis resulted into the search for (i) co-operative environmental policies; (ii) regional economic improvement; (iii) rational resource planning; (iv) increased public awareness of environmental and ecological problems, and (v) the rise and importance of public action (voluntary organisations and movement to protect the environment such as **chipko movement** in India).

(5) **Present Phase** : Present phase of the perception of resource availability and management is characterized by growing concern for resource inadequacy caused by exponential growth in the world-wide use of many precious resources such as fossil fuels, industrial metal ores, forest resources etc. All these have resulted into shortage of certain resources (e.g. fossil fuels, metal ores etc.) and environmental degradation, and expansion and urban growth leading to ecological imbanace and ecosystem disequilibrium has necessitated the urnest need of resource conservation and management.

22.3 CLASSIFICATION OF RESOURCES

1. Dasmann's (1976) Classification

Resources are generally divided into two broad categories as follows :

(1) natural/environmental resources, and

(2) non-utilitarian resources.

(1) **Natural Resources** : Natural or environmental resources are those which belong to natural environment and include both biotic (such as plants and animals including micro-organisms) and abiotic (such as land, air, water, soils, minerals etc.) resources. Natural resources are classified into the following 4 categories :

(i) inexhaustible natural resources,

(ii) non-renewable natural resources,

(iii) recyclable natural resources, and

(iv) renewable natural resources.

R.F. Dasmann (1976)

(2) **Non-Utilitarian Resources** : non-utilitarian resources are those which do not have practical values such as natural resources have, rather these have social and ethical values e.g. two groups of people having different standards of living, have different perception and outlook towards environment. For example, a society of people having sound economy, better education, and high standard of living would require better environmental quality in terms of fresh air, clean water etc. but simultaneously would generate more solid waste substances due to greater use of modern amenities while the other society of people having poor economy, poor education and low standard of living may not care for environmental quality because they would be more interested in filling their bellies. Such resources, thus, include education, recreation, scenic

beauty, ideologies and philosophy, culture etc. R.F. Dasmann (1976, in C.C. Park, 1980) has given the meaning of 4 types of natural resources as given in table 22.1

Table 22.1 : Meaning of natural resources according to R.F. Dasmann (1976)

Resource type	Characteristics and examples
1. Non-Renewable Resources	'Are not generated or reformed at rates equivalent to the rate of which we use them'. When these resources are gone, there is no hope of their replacement e.g. wild-life.
2. Recyclable Resources	'A special type of non-renewable resources-which are not lost or worn out by the way we use them and can be reprocessed and used again and again e.g. metals.'
3. Renewable Resources	'All living things that have the capacity for reproduction and growth. As long as the rate of use is less than their rate of regeneration and as long as their environments are kept suitable, they will go on replacing themselves. However, living communities are not necessarily renewable, if the way in which we use them is destructive. No living species can survive if we crop it at a rate more rapid than it can reproduce or if we destroy the habitat in which it depends'. For example, several animals (like Indian lions) and birds have now become endangered species and are facing their extinction because of destruction of their habitats through deforestation and environmental degradation.
4. Inexhaustible Resources	'Those such as sunlight, which will continue to pour onto the earth as long as humanity will be around, whether we use it in certain way or not'. Water, and wind are other examples of inexhaustible natural resources.

Source : R.F. Dasmann, 1976 : Environmental Conservation, Wiley, New York, (in C.C. Park, 1980).

2. O.S. Owen's (1971) Classification

O.S. Owen (1971) has classified the resources into 2 major categories. His classification is based on quantity, mutability and resusability of resources.

(1) inexhaustible resources
    (i) misusable resources
    (ii) immutable resources
(2) exhaustible resources
    (A) maintainable resources
        (i) renewable resources
        (ii) non-renewable resources
    (B) non-maintainable resources

Table 22. 2 : Classification of resources according to O.S. Owen (1971)

Resource Type	Characteristics and examples
I. Inexhaustible Resources	Those resources which would never fall short of demand at world scale so long as the present planetary system exists, e.g. sunlight, water, wind etc.
(A) Immutable Resources	Those resources which are most likely not to be adversely changed by human activities e.g. water resource.
(B) Misusable Resources	Little danger of complete exhaustion but when used improperly the quality of resources may be impaired and degraded (e.g.

	water). Even the desired quality of sunlight for the survival of human beings may be degraded by increase in greenhouse effect and depeletion of ozone layer by human activities (substantial increase in solar radiation).
II Exhaustible Resources	Those resources which may face complete exhaustion if used at far greater speed than the rate of their generation such as fossil fuels (coal, mineral oil, natural gas), mineral ores etc.
(A) Maintainable Resources	include those resources the permanency of which depends upon methods of their utilization by man such as forest resource, wildlife, soil fertility etc.
(i) Renewable Resources	include living things such as plants and animals and even man and some non-living things such as soils and their fertility. If properly used and managed ecological resources continue to reproduce and thus replenish them but if used improperly they may be completely exhausted. For example, if forests are recklessly removed without simultaneous reforestation and afforestation they may be completely exhausted, as has happened in many parts of the world. Similarly if no proper crop and soil management is practiced, soil may lose its fertility and even its productive property.
(ii) Non-renewable Resources	include those resources which if gone due to over-exploitation, may not be replaced again e.g. wildlife.
(B) Non-maintainable Resources	include most of the mineral resources whose quantity is fixed and static. Such resources are also considered as wasting assets. These mineral resources cannot be replaced after their destruction or consumption.
(i) Reusable Resources	are those minerals whose reuse potential is much higher than consumptive usage e.g. gem minerals-diamond.
(ii) Non-reusable-Resources	are those mineral resources whose consumptive use is of very high value. Such minerals are lost after use and their reserves are fixed, so their exhaustion is certain e.g. fossil fuels-coal, mineral oil, natural gas.

Source : O.S. Owen, 1971 : Natural Resource Conservation : An Ecological Approach (Macmillan), New York.

Owen's classification of resources is based on quantity, mutability and reusability of resources as is evident from table 22.2. Owen has also suggested conservation principles for resources but different conservation principles and methods are required for exhaustible and inexhaustible resources.

3. General Classification

On an average resources are divided into the following 6 categories :

(1) biotic and abiotic resources,

(2) exhaustible and inexhaustible resources,

(3) potential and developed resources,

(4) raw material and energy resources,

(5) agricultural and pastoral resources, and

(6) mineral and industrial resources.

(1) Biotic and Abiotic Resources

(i) Biotic resources comprise living things such as plant resources and animal resources.

Biotic resources are also called as **ecological resources.** Plant or floral resources include forests and their products, agricultural crops, animal fodders etc. Animal or faunal resources comprise wild and domestic animals, birds and fishes and animal products. The most significant characteristic resources are renewable but the renewability depends upon the species and environmental conditions of habitats of these resources. For example, agricultural crops are annually renewable provided that the geographical conditions do not change significantly. On the other hand, perennial trees have very low renewability because of exceedingly low reproductive rate.

(ii) **Abiotic resources** include non-living things of the biospheric ecosystem such as land, water, soils, rocks and minerals. Sunlight, air, water etc. are renewable and inexhaustible abiotic resources while most of the mineral resources are exhaustible and non-renewable such as coal, mineral oil and natural gas. Some of the mineral resources are abundantly found (e.g. iron and bauxite) whereas some are scarce (e.g. gold, silver, platinum, uranium and other atomic minerals). Some mineral resources are also renewable such as managanese.

(2) Exhaustible and Inexhaustible Resources

(i) All non-living things, such as minerals, which are extracted from the earth are grouped under the category of **exhaustible resources** e.g. fossil fuels (coal, mineral oil and natural gas), mineral ores (iron ore, copper, bauxite, atomic mineral etc.) etc. Both metallic ores (e.g. iron, copper, tin, bauxite, lead, zinc, gold, silver, antimony, platinum, manganese, nickel, cobalt, uranium, titanium, thorium etc.) and non-metallic minerals (such as mica, asbestos, graphites, phosphate, sulphur, gypsum, potash etc.) are fixed in quantity and thus over-exploitation of these mineral resources leads to their complete exhaustion.

(ii) **Inexhaustible resources** are perennially renewed by reproduction, or by physical, chemical or mechanical processes. Such resources include solar energy, water, wind, most of wildlife and human beings. A few rare species of animals are not inexhaustible (such as lions, tigers) because their reproduction rate is very slow. It may be mentioned that in reality even solar energy is also not inexhaustible because life of the sun is also finite (6 billion years). Water and wind also become exhaustible if they are heavily polluted by human activities.

(3) Potential and Developed Resources

Total amount of energy inherent in a particular resource (e.g. water) is called as potential energy and the resources which are capable of producing maximum energy are called as potential resources e.g. water power resources (running water from rivers, streams, and melting glaciers) and solar power resources. The quantity of potential energy which has been developed by man for his uses is called as developed energy and the quantity of resource which has been actually harnessed for the generation of energy (such as hydroelectricity, solar power) is called developed resource.

(4) Raw Material and Energy Resources

Raw materials are those primary resources which are used in the industries for manufacturing of goods. Raw material resources are further divided into two broad categories as follows :

(i) biotic raw materials or ecological raw materials, and

(ii) abiotic or mineral raw materials.

Biotic or ecological raw materials are derived from forests, agriculture, fishing and animals while mineral raw materials (e.g. fossil fuels, mineral ores, atomic minerals, gem minerals etc.) are derived from the earth through mining. Energy resources are those resources which are used to produce power or energy to run machines and automobiles. The resources which produce heat and power include fossil fuels (coal, mineral oil and natural gas), atomic minerals, geothermal energy, tidal energy, water energy and solar energy. Energy resources are further divided into (i) non-renewable energy resources (e.g. coal, mineral oil, natural gas, geothermal energy, and atomic minerals), and (ii) renewable energy resources (direct solar energy, water power, wind power, biomass energy and tidal energy).

(5) Agricultural and Pastoral Resources

Agricultural resources include both agricultural lands as well as agricultural products. Agricultural resources are also called as basic resources because these resources meet the basic needs of human beings (food, clothing and shelter) and also provide fodder and solid food (grains) to the domesticated animals. Besides, agricultural resources also provide raw material to agro-based industries. Pastoral resources include food items and raw materials for textile, foot wear, leather and food processing for various purposes. Food items derived from pastoral resources include meat (pork, beef, mutton, lamb, chicken etc., milk, butter, cheese etc. By-product resources are hides, hairs, wool and bones.

(6) Mineral and Industrial Resources

Mineral resources fall in 3 broad categories :

(i) metallic mineral ores,

(ii) non-metallic minerals, and

(iii) fossil fuel minerals,

(i) Metallic mineral ores include iron ore, copper, lead, tin, zinc, bauxite (aluminum), silver, gold, nickel etc., (ii) non-metallic minerals are mica, asbestos, graphite, sulphur, diamond, phosphate, potash, gypsum etc. and (iii) fossil fuel minerals include coal, mineral oil and natural gas. Industrial resources fall in 4 broad categories viz. (i) mineral resources as referred to above, (ii) agricultural resources e.g. agricultural crops and their products, (iii) pastoral resources e.g. animal products, and (iv) industrial by-products.

22.4 ECOLOGICAL RESOURCES

'Ecological resources...... refer to all plant and animal resources in terms of individuals, species, communities, habitats and ecosystems, other than managed specifically for financial gain (such as commercial forestry operations and agriculture in general)' (C.C. Park, 1980). Ecological resources, in fact, are considered to be the 'real wealth of nations'. Primary productivity (productivity of autotrophic green plants) determines the dimension of ecological resources because the richness of other environmental resources (primary consumers herbivorous animals and secondary consumers carnivorous and omnivorous animals including man) depends upon primary production of plant communities.

1. Classification of Ecological Resources

Ecological resources are generally divided into the following two categories :

(1) Plant or floral resourcees, and

(2) Animal or faunal resources.

But more specifically ecological resources, as per definition of ecological resources given by C.C. Park (as referred to above), are divided into two main types :

(1) Natural or wildlife ecological resources, and

(2) Managed ecological resources.

(1) Natural Ecological Resources

Natural ecological resources, also called as wildlife ecological resources, include plant and animal resources of those natural ecosystems which have not been affected by human activities such as solar powered and nature-subsidised ecosystems of E.P. Odum (1975, see chapter 5, subsection 5.2 (v). It may be pointed out that it is difficult to find out pure ecosystem as all the ecosystems known on the planet earth have been approached by man. Even Antarctica has become a busy centre of experiments of various sorts by various nations. Thus natural ecological resources include those plants and animals which are cared by nature but now some of the endangered species of plants and animals are managed by man in protected areas such as nature reserves, national parks, sanctuaries etc. Vegetation communities are most significant resource base for human society because plants being primary producers provide food to all faunal communities including human beings.

(2) Managed Ecological Resources

Managed ecological resources mean agricultural crops, other plants and animals which are domesticated by man. Such resources include plants and animal resources of those ecosystems which represent man-subsidized solar-powered natural ecosystems and managed by man-such as commercial and social (community) forests and agricultural crops, milch animals, sheeps and goats, and other animals which are reared for commercial purposes mainly in agriculture sector.

2. Importance of Ecological Resources

Ecological resources are very important elements of the natural ecosystems because their stability and survival largely depend upon ecological resources. Unwise and over-exploitation of ecological resources and destruction of natural habitats lead to environmental degradation and pollution and thus natural ecosystems become disturbed and destabilized. It is, therefore, necessary to pay more and more attention towards the preservation, conservation and management of ecological resources so as to maintain ecological balance and ecosystem equilibrium so that the survival of humanity may be assured.

Recently, more interests have been shown in the preservation and management of ecological resources because of their intrinsic value, aesthetic value, social benefits, scientific value, recreational and educational significance and overall environmental value because the stability of natural ecosystems depends upon ecological balance. D.R. Helliwell (1969) has shown that interests in the ecological resources are increasing world over because of various benefits of ecological balance as given below :

- ➤ direct returns from ecological resources such as direct material and monetary returns from hunting (now prohibited), shooting (hunting and shooting of wild animals have now been banned), fishing and food gathering.
- ➤ genetic reserve (preservation of natural ecosystems and their ecological resources help in the breeding of new varieties of crop-producing plants, and animals).
- ➤ ecological balance (maintenance and preservation of natural species and population of plants and animals help in maintaining the richness of biodiversity, widening the food chains and ecological balance and ecosystems stability).
- ➤ educational value: direct education of children about natural plants and animals and their ecological functions.
- ➤ research value : natural ecosystems and ecological resources may serve as museums and laboratories of research of biological communities, their functions and problems.
- ➤ natural history interest : natural ecosystem may help in tracing the evolutionary history of biological world.
- ➤ local value : ecological resources decide the characteristics of the place and area concerned.

22.5 RESOURCE USE AND ENVIRONMENT

The natural environment has provided plenty of abiotic (mineral) and biotic resources to human society and different segments of society have evolved and developed through the exploitation and utilization of natural resources since man began sedentary life but the development of scientific knowledge and advancement in technology have led to accelerated rate of exploitation and use of natural resources resulting into environmental degradation and ecological imbalance.

The environmental problems of various sorts emanate at three sources during different stages of uses of natural resources as follows :

- ➤ at explaitation stage,
- ➤ at manufacturing and processing stage, and
- ➤ at consumption stage.

The environmental problems arising out of man's interactions with the environment (exploitation and utilization of natural resources) have been discussed in historical perspectives in chapter 3 (section 3.3) and causes of environmental degradation have been described in chapter 20 of this book. This apect is not being discussed in order to avoid repetition. However, briefly it may be restated that the following human activities while using environmental (natural) resources lead to environmental degradation and ecological imbalance :

- ➤ Land use changes for various purposes mainly felling of trees for commercial purposes (deforestation), building and construction activities such as construction of roads along forested hillslopes cause accelerated rate of soil erosion, reduce biological diversity (biodiversity) etc.

- Use of river water by constructing large dams and impounding of immense volume of water in big reservoirs behind the dams for the generation of hydroelectricity and for irrigation purpose causes submergence of extensive natural ecosystems having large number of plants and animal species and hence rich biodiversity but this human action causes decrease in biodiversity and ecological imbalance.
- Extraction of large quantity of groundwater for drinking and irrigation purposes causes on one hand, depletion of groundwater resource and results in the formation of large cavities below ground surface and resultant fissures in the ground surface and collapsing thereof, on the other hand.
- Large-scale mining creates huge amount of waste materials on the surface of the earth which create problems of various sorts e.g. accelerated rate of soil erosion, silting of river beds and consequent increase in the frequency and dimension of river floods.
- Manufacturing and processing of raw materials derived from the nature in numerous mills create waste materials which cause environmental problems of various sorts. For example, sugar mills create mountains of bagasses and unbearable foul smell of molasses.
- Manufacturing and processing industries using fossil fuels (coal, diesel, natural gas) emit a number of gases which pollute ambient air. The particulate matters coming out of chimneys of mills not only pollute air by forming veils of dusts and smokes in the lower atmosphere but also change global radiation balance.
- Ever-increasing use of fossil fuels in automobiles releases immense volume of carbon monoxide, carbon dioxide, nitrogen oxides etc. which not only change atmospheric chemistry but also increase greenhouse effect and resultant global warming leading to climate changes.
- Water (surface water—river, pond and tanks, lakes) is being heavily polluted due to outfall of sewage drains coming out of urban and industrial centers into these water bodies. Groundwater is being polluted at alarming rate due to downward movement of dangerous chamials of chemical fertilizers, biocides and insecticides which are heavily used for increasing agricultural productivity of land, and agricultural production (crop yield). Many of the Indian rivers have been so greatly polluted that their water is not only unsafe for human use but has also become unsuitable for animals and irrigation (see chapter 25, Environmental Degradation and Pollution in India).
- Urban and industrial wastes, and domestic waste substances create a number of environmental problems.
- The extraction and processing of radioactive minerals such as uranium, thorium, monazite etc. create environmental hazards if not properly guarded and protected.
- Many more examples may be cited for rapacious exploitation of natural resources, wasteful use of such resources and serious environmental problems emanating therefrom.

It may be summed up that irrational exploitation and consumption of natural resources have given birth to a number of serious environmental problems which have threatened the existence of even human society. A few of them are listed below :

(1) changes in atmospheric chemistry, global warming and consequent climate changes, increase in the incidence of tropical cyclones, mainly in the Caribbean Sea (like Katrina, Wilma etc., 2005), decrease in the strong spells of Indian monsoon since 1950, increase in summer temperatures in Europe and USA since 2000 A.D. etc.

(2) decrease in biodiversity mainly in tropical rainforests, increase in the incidence of coral bleaching and hence phenomenal decrease in biodiversity of coral ecosystems.

(3) phenomenal increase in air pollution over big cities worldover.

(4) increased water pollution mainly of river and lake water, loss of biological communities in many rivers which receive polluted urban and industrial sewage water.

(5) accelerated rate of soil erosion consequent upon deforestation and resultant silting of river beds and consequent increase in the frequency and dimension of floods of alluvial rivers.

(6) degradation of coastal ecosystems due to reclamation of swamps and marshes, backwaters, destruction of coastal dunes and mangrove forests which are the frontline natural buffers against storm surges and tsunami waves.

(7) decrease in agricultural productivity due to excessive use of chemical fertilizers, pesticides and insecticides.

The main causative factors of aforesaid, and many more, environmental problems are related to irrational use of natural resources and unplanned and unsustainable development. The proper management of natural resources requires rational exploitation and optimum utilization of natural resources keeping the ecological principles, which lead to sustainable environment and ecosystem, and sustainable society and development, in mind. These aspects would be elaborated in the succeeding (23rd) chapter.

23

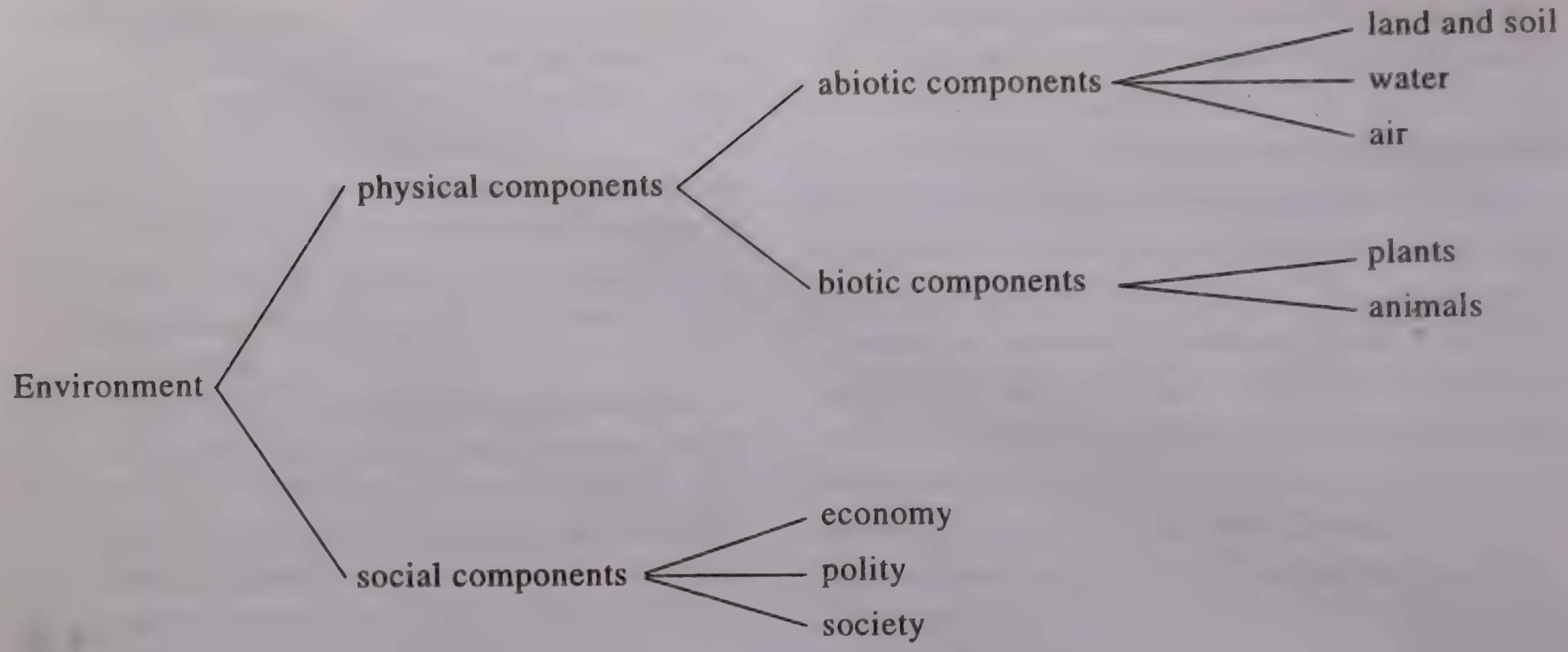
ENVIRONMENTAL PLANNING AND MANAGEMENT

Environmental planning and management is a comprehensive discipline which considers all aspects of interactive processes between man and environment (exploitation and utilization of environmental/natural resources), environmental problems arising therefrom, and control and management thereof. The physical (natural) environment has limited assimilative and carrying capacity against everincreasing exploitative economic activities of man which exceed the threshold of homeostatic mechanism of environmental system leading to emergence of environmental problems of various sorts. Management is a broad discipline ecompassing several disciplines involving environmentalists and ecologists, economists, sociologists, politicians, administrators who view management quite differently. It is thus imperative to define certain terms before attempting discussion on various aspects of environmental management as follows :

- environment,
- development,
- gaiya hypothesis,
- sustainability,
- sustainable development,
- environmentally sensitive development,
- sustainable environment,
- planning, and
- management.

Environment

The sum total of physical (both abiotic and biotic components) and social elements of particular location on the earth's surface at a specific time span is called environment. The following are basic components of environment :



Development

It is difficult to provide an universally acceptable definition of development because people of different disciplines view development differently. Development is a goal and process of change aimed at the betterment of life style of human beings.

Development may be defined as a **'process of change'** in the society in terms of economic growth and prosperity with anthropocentric view point. The term 'change' in the definition of development is used in wider sense so as to include positive material, social and organizational changes leading ultimately to achieve the **'goal'** of economic growth, eradication of poverty and inequality both economic and social. There are two view points regarding development :

- anthropocentric view point, and
- ecocentric view point.

Anthropocentric view point of development as advocated by economists places man in the forefront while environment occupies back seat, meaning thereby material growth of human society is of primary consideration.

Ecocentric view point of development as advocated by environmentalists and ecologists place maintenance of environmental quality and ecological balance, and improvement of quality of life style of humans and material growth on equal footing. This view point also emphasizes maintenance of critical environmental and ecological processes. It is apparent that ecocentric view point of development is based on Gaia Hypothesis.

Gaia Hypothesis

Gaia hypothesis, later on developed as Gaia theory, postulated by British biologist James Lovelock in early 1970s, after the name of Greek goddess, emphasizes the need to strike a balance between human needs and development on one hand, and the maintenance of environmental quality on the other hand as the hypothesis says that 'human needs must be weighed against maintaining critical natural processes'.

Originally, Lovestock and his associate Lynn Margulis postulated that 'life on earth actively keeps the surface conditions always favourable for whatever is the contemporary ensemble organisms'. That is 'life on earth, instead of adapting itself to the given climatic conditions as earlier believed, actually modified the conditions to suit its survival and further evolution' (Hindu, July, 2006).

Sustainability

The ecocentric approach to development management emphasizes ecological balance and human material growth in long term perspective. It may be remembered that neither of these two viz. ecological system and human institutions are everlasting as these have to come to an end, the time of which is not known. In fact, the longevity of human institutions depends on the stability of ecological system which itself depends on human ability and desire to maintain ecological balance. In the background of this concept sustainability may be defined as follows :

'Sustainability is a concept that denotes the ecological functions and steady demands of ecological resources so that there may be continuous supply of ecological resources for development management on one hand, an ecological balance on the other hand.'

Sustainable Development

Sustainable development denotes material growth of humans and improvement in life style with growing demands of ecological resources and maintenance of environmental quality and ecological balance.

G.H. Harlem (1987) has defined sustainable development as follows :

Sustainable development may be defined as an approach 'to meet the needs and aspirations of the present without compromising the ability to meet those of future.'

W.P. Cunnigham and M.A. Cunnigham (200) have defined sustainable development in the following manner :

'Sustainable development, then, means progress in human well-being that we can extend or prolong over many generations, rather than just a few years. To be truly enduring, the benefits of sustainable development must be available to all humans and not just to a priviledged group'.

The concept of sustainable development probably came in 1970 but it became known to wider section of society with the publication of 'Limit to Growth' by the Club of Rome. Soon the concept of sustainable development was preferred to 'Zero Growth' by general public.

Sustainable development concept is used in a variety of sense as follows :

(1) Sustainable development as a goal → to achieve
- economic growth
- environmental protection
- health and hapiness

(2) Sustainable development as a theory or paradigm → to intergrate
- socio-economic growth
- environmental management

(3) Sustainable development as a practice → to find
- effective sustainable development strategies
- good governance
- to strike balance between human material growth and quality of life and preserving environmental quality

Environmentally Sensitive Development

Environmentally sensitive development (ESD) is defined as rational exploitation and optimum utilization of natural/ecological resources in long-term perspective so that use of resources may be maintained indefinitely without compromising with ecological stability and social order, so that human well-being is maximised and damage to environment is minimised.

Sustainable Environment

Sustainable environment may be defined as such an environment whose physical and biotic components remain in healthy condition inspite of exploitation and utilization of natural/ecological resources in long-term perspective. Such sustainable environment, which may assure continuous yield of natural resources to coming generations, may be maintained only when the human society, more specifically the planners, managers, administrators and politicians follow the rules of ecological principles and Gaia hypothesis.

Planning

Planning is considered as a process of development having two main objectives e.g. (1) achieving the overall growth of the society, and (2) removing socio-economic disparities through the exploitation and utilization of all types of resources whether natural or human.

Planning → a process of development → to
achieve overall growth of human society
remove socio-economic disparaities

↓
through

- exploitation of all types of resources
- utilization of resources

Management

"Management implies a conscious choice from a variety of alternative proposals and further more than such a choice involves purposeful commitment to recognized and desired objectives. Wherever possible, management implies to the deliberate adoption of a strategy or number of strategies designed to meet realistically short term objectives, yet specifically providing sufficient flexibility for the preservation of longer term options"(T.O. Riordan, 1971).

23.1 ENVIRONMENTAL MANAGEMENT

Environmental management is viewed differently e.g. as a **concept** of total picture of environment; as a **science** of management of environmental (ecological) resources or as a **science** of management of natural/environmental (both abiotic and biotic resources) resources; as a **model** of planning and management of environmental problems; as a **methodology** involving interlinked processes of management of ecological resources and problems arising out of interactions between human economic activities and various components of natural environmental system; as a **process** of striking balance between resource use and maintenance of environmental quality and ecological balance; as an **approach** towards achieving the goals of sustainable development, sustainable environment and sustainable society by adopting ecological principles and by striking a balance between anthropocentric and ecocentric view points of development. Thus, environmental management needs discussion on the following aspects;

- meaning and concepts,
- historical perspective,
- objectives and goals,
- needs and taboos,
- approaches and methods,
- ecological basis of resources management
  - (a) classification and survey of ecological resources
  - (b) evaluation of ecological resources
  - (c) conservation and preservation
- environmental monitoring,
- environmental audit,
- eco-accountability,
- eco-regulation, and
- environmental impact assessment.

Environmental Management : Meaning and Concepts

As stated earlier **planning** is a process of development having two-fold goals e.g. (1) achieving overall growth of human society, and (2) removing socio-economic disparities through the exploitation and utilization of all types of resources whether natural or human having anthropocentric view point.

On the other hand, **environmental planning** is the process of eco-development with ecocentric view points having main goal of overall growth of human society and maintenance of environmental quality and ecological stability through rational exploitation and optimum utilization of natural resources so as to achieve sustainable development, sustainable environment and sustainable society.

It may be mentioned that the use of non-renewable resources, such as minerals and fossil fuels, cannot be sustainable because once used these cannot be regenerated and renewed. Thus, sustainability becomes effective only in the cases of renewable resources i.e. ecological resources but some of abiotic resources such as water, wind etc. are also renewable and hence sustainable.

Environmental management, in fact, is difficult to define because even the term environment in itself is complex as it is understood and interpreted differently by different sections of society; the objectives of the management of environment are complex, varied and even conflicting, and the alternative strategies are divergent.

"The concept of environmental management is generally related with the environmental model which assures that food supply will grow with increased capital, annual agricultural inputs, and land development; but on the other hand it also includes important limits to all these factors, challenges to be faced and the policies to overcome the problem." D. Medows (1997)......(1)

If may be pointed out that ecological balance and ecosystem stability are duly maintained by the nature itself through **'homeostatic mechanism'** but the emergence of modern industrial society has disturbed the ecological balance and ecosystem stability through heavy industrialization, technological revolution, faster growth of means of transportation and communication, rapacious exploitation of natural resources, large-scale land use changes, unplanned and unchecked expansion of urban and industrial complex etc. In other words, human activities of modern 'economic and technological man' have disturbed the harmonious relationships between the environment and man.

'Environmental management is, thus, the process to improve the relationship between man and environment so that the quality of both, the environment and human society, may be improved. This improvement of relationships between man and environment may be achieved through check on destructive activities of man, conservation, protection, regulation and regeneration of nature.'

Savindra Singh (1991)......(2)

Environmental management, thus, is related to the rational adjustment of man with nature involving judicious exploitation and utilization of natural resources without disturbing the ecological balance and ecosystem equilibrium. It may be pointed out that since the development of society in terms of socio-economic framework has to be maintained and hence it is imperative to utilize natural resources. If the natural resources are exploited, some environmental problems are bound to crop up because no gainful exploitation of natural resources and hence socio-economic development of a nation is possible without causing injury to some of the components of the nature/environment.

'Environmental planning and management is, therefore, compromise between ecosystem and ecological balance and human material progress and thus environmental management must take into consideration the ecological principles and socio-economic needs of the society.'

Savindra Singh (1991)......(3)

Environmental management, thus involves socio-economic development of the society on the one hand, and maintenance of environmental quality on the other hand. It may be further pointed out that the term 'environmental quality' is also difficult to be defined because it is a subjective term and is interpreted differently by different groups of people ranging from 'zero population growth' to simplicity of life for decent human existence, from the survival of human species to an environment that not only sustains life but enriches life, harmonising the work of man and nature for the greater good of all (M.W. Mikesell, 1974).

Environmental management, therefore, involves the following aspects :

- ➤ Protection of environment through putting curb on rapacious exploitation and utilization of natural resources and unscrupulous activities of man, control and lowering down of pollution level, control of rapid growth of human population and environmentally harmful technologies.

- Enhancement of economic value of environment and its resources, and
- Preservation of nature and environment for our future generations.

"Conservation of resources and control of pollution are the essential prerequisites for environmental planning. Conservation does not mean stoppage of development activities; rather it adds value to the available resources through appropriate technology and, thus, accelerates growth processes. In fact, conservation and development are the two facets of the same coin and thus are complementary to each other. No growth in true sense would be attained unless appropriate technology is evolved to get maximum return out of a tiny bit of resource and avoid wastage and depletion (of natural resources) and devise scientific methods of recycling so as to cause least burden over the environmental system" (L.R. Singh et al. 1983).

It is evident from the aforesaid discussion that environmental management involves two basic aspects :

- socio-economic development of society, and
- stability of the biosphere in general and stability of individual ecosystems in particular.

The following definitions widen the horizon of environmental management :

Thompson viewed environmental management as 'the system that anticipitates and avoids or solves environmental and resource conservation problems'

D. Thompson (2002)......(4)

The above definition has focussed on future problems (anticipatory role of environmental management) of environment arising out of resource use and solution thereof.

El-Kholy views environmental management as 'a process concerned with human-environment interactions, which seek to identify what is environmentally desirable; what are the physical, social, economic and technological constraints to achieving it; and what are the most feasible options.'

O.A. El-Kholy (2001)......(5)

'Environmental management is concerned with meeting and improving provision for human needs and demands on a sustainable basis with minimal damage to nature'.

C.J. Barrow (2005)......(6)

Based on above discussion the author opts to provide the following comprehensive definition of environmental management.

'Environmental management is a goal and process of ecodevelopment having a balance between anthropocentric and ecocentric view points of development leading towards sustainable development, sustainable environment and sustainable society through rational exploitation and optimal utilization of natural resources in long-term perspective so that availability and use of resources may be maintained continuously and there is no ecological imbalance and social disorder, so that human well-being is maximised and damage to environment is minimised'.

Savindra Singh (2007).........(7)

"There are healthy sings that decision makers responsible for environmental planning and management are becoming increasingly aware that the stability of the biosphere in general and the survival and stability of individual ecosystems in particular, are criteria which need careful consideration when environmental management policies and priorities are being evaluated and implemented." (C.C. Park, 1981).

Environmental Management : Historical Perspective

The environmental management gained currency in the decades 1960s and 1970s when serious environmental problems like ozone depletion, global warming, pollution of various sorts arising out of excessive and irrational exploitation of natural resources and increased use of productive technologies caught the eyes of developed nations. Consequently, efforts were made by government officials and technocrats to control environmental degradation and pollution following **'top down approach'** of environmental management but the management of environmental issues and problems was sectoral and discrete in character rather than an integrated and comprehensive approach. In fact, **monistic concept** and not the **holistic concept,** was in the core of environmental management. In other words, individual environmental problems and not the total problems, at different spatial scales such as at local, regional and global levels were taken care of through strict laws, rules and regulations and their forceful implementation (e.g. control and management of fisheries, whildlife, mining, pollution, agriculture and soil pollution, deforestation and soil erosion etc.). In the beginning people's involvement and people empowerment was not given due importance in environmental management.

Later on environmental management became a science based on holistic approach to the solution of environmental problems having **'bottom-up approach'** of environmental management having five environment-development paradigms (as suggested by M.E. Colby, 1991, in his research article entitled, 'environmental management in development : the evolution of paradigms') as follows :

- **Frontier economics :** The paradigm of frontier economics was based on teleological approach towards man-environment relationship and economic deterministic theory. Since the natural resources are infinite and the nature has limitless sinks to accommodate wastes coming out of resource use, there is no need of environmental management. This paradigm lost its relevance after 1960. Now, there is growing need for **'green economics'**.
- **Deep ecology :** simply means maintenance of ecological stability by conserving **'deep greens'** (vegetation and wildlife). This paradigm is based on ecocentric view point of development, say sustainable development and sustainable environment. This approach to environmental management pleaded harmony and not hostility between man and nature.
- **Environmental protection :** There was mass awakening about serious environmental problems such as ozone depletion, environmental pollution, loss of biodiversity and many more after 1960 and hence environment and development were taken two sides of the same coin and thus environmental protection was given due attention. A few tools of environmental protection such as **environmental impact statement** (EIS) and **environmental impact assessment** (EIA) were developed and were made mandatory before any development project was approved and launched.
- **Resource management :** In the decades 1970s, or say late 1960s, there emerged a concern about the fear of depletion of natural resources if the irrational and rapacious utilization of natural resources was not checked properly. Consequently, a need for proper management of natural resources was emphasized and thus it became necessary to properly study and assess various aspects of natural resources, such as renewability or non-renewability and regeneration before launching any development plan. The publication of 'Limits to Growth' by D.H. Meadows and his associates in the year 1972, well supported the concept of resource management in the light of finite nature of resources and very slow geological processes of the formation of key minerals such as metals and fossil fuels.
- **Ecodevelopment :** The concept of 'ecodevelopment' was evolved in the year 1981 by R. Ridell, which appeared in his publication 'ecodevelopment : economics, ecology, and development.' This paradigm laid emphasis on 'sustainable development', 'sustainable environment', and 'sustainable society' with the following goals :
    - ✱ to achieve overall growth of human society,
    - ✱ to remove socio-economic disparity,
    - ✱ to maintain environmental quality and ecological stability, and
    - ✱ to maximise economic growth and quality of life style of society, and minimise damage to environment.

Environmental Management : Objective and Goals

The ultimate goals of environmental management are to achieve 'sustainable development', 'sustainable environment', and 'sustainable society' which are based on the following objectives of environmental management.

- ✱ to make rational exploitation of natural resources in tune with ecological principles and criteria of sustainability.
- ✱ to make optimal utilization of natural resources.
- ✱ to restrict and regulate exploitation of natural resources.
- ✱ to maximise human well-being and minimise damage to environment.
- ✱ to improve human adaptability to environmental and socio-economic challenges.
- ✱ to regenerate the degraded environment and depleted ecological resources.
- ✱ to cope with changes in public outlook, fashion and demand, economic and technological situations, scientific and technological capability, social values and ethics, open world market and globalization etc.
- ✱ to deal with besides physical data (data regarding physical environment), historical data (historical perspectives of changes in man-environment relationship), policy formulation, social data, institutional problems etc. while attempting environmental management.
- ✱ to assess impacts of development projects on environment.
- ✱ to control environmental degradation and pollution.
- ✱ to review and revise exhisting technologies and strategies of management.
- ✱ to mitigate and reduce impacts of natural hazards and disasters.
- ✱ to formulate laws and to ensure effective implementation of environmental managemental plans.

The goals and objectives of environmental management are based on the following model :

Needs :
aspirations, perceptions, priorities, inhibitions } of < individuals, society, government

Environmental Management : Obstacles and Taboos

Though environmental management is greeted now with no major hostile objections but there are certain hurdles in the implementation of certain management plans from local to regional and global levels. For example, majority of world community accepts the reality of global warming and related climate change due to ever-increasing greenhouse effect caused by emission of greenhouse gases mainly carbon dioxide at alarming rate but a few nations (mainly USA and Australia) do not accept the possibility of future climate change due to global warming and are avoiding to sign Kyoto protocol on emission of carbon dioxide, though summer temperature is rising in European countries and in the USA and hundreds of people are dying from heat strokes since 2001. A few of such hurdles in the implementation of environmental management plans are given below :

- ➤ regulations of WTO, open market and globalization and political pressure under the garb of environmental politics from certain developed nations,
- ➤ poverty, backwardness, debt burden from WB and IMF in the developing countries,
- ➤ rapid growth of human population in underdeveloped and developing countries,
- ➤ rapid rate of industrialization and urbanization and consequential rapid increase in the demand and consumption of natural resources,
- ➤ rapid changes in social outlook and values, spread of western culture of life style-'use and throw away culture',
- ➤ political compulsions and bad governance,
- ➤ limitations in inforcing environmental laws and regulations,
- ➤ social and religious impediments, etc.

Environmental Management : Methods and Approaches

'Methodology is like a **'battle plan'** and techniques the **'type of weapon used'** (C.J. Barrow, 2005) whereas approaches are paths leading towards a destination (here a goal or goals of environmental management). These days environmental management needs **'proactive/anticipatory approach'** with

predictive tools. Proactive approach to environmental management is based on the skill of anticipation of environmental problems to occur and hence there should be proper ways of predictions of certain problems arising out of uses of natural resources in a number of ways such as mining, harnessing of river water in big reservoirs behind the dams etc. Besides, there are a few other approaches to environmental management based on certain objectives and goals.

At the very outset it may be mentioned that environmental planning and management should include the entire biological world because environment belongs to man and all living organisms which except man do not know any artificial boundary whether regional, national or international. But the same strategy and approach for environmental management may not be applicable to all the regions and all of the ecosystems because human interests differ in different regions and ecosystems. For example, overpopulation and related problems (e.g. economic poverty, retarded economic growth, social and educational backwardness) are the main areas of concern in the developing countries whereas high level of pollution and environmental degradation caused by advanced technologies, increased production, materialistic outlook and resource depletion are the immediate issues to be tackled in the developed industrialized western countries. A few approaches are given below :

(1) Approaches based on spatial consideration

The strategies of environmental management may be formulated on the basis of spatial consideration i.e. the size of area selected for environmental management.

Spatial Approach
- ● local level
- ● regional level
- ● global level

(2) Approaches based on methodological consideration

Methodological consideration includes the following 3 basic points.

- ✱ Environment is a closed system,
- ✱ Environmental/natural resources are finite, and
- ✱ Environment is a natural gift and thus is a public property.

Based on above there are two approaches of environmental management as follows :

Ecological Approach
- ● **Conservation approach**
  - ➤ to optimise production, and
  - ➤ to minimise damage to environment
- ● **preservation approach**
  - ➤ to protect endangered species, both plants and animals
  - ➤ to stop use of ecologically threatened and endangered species

(3) The environmental management may be approached through strategies of implementation of management plans and how to make them effective in two ways as follows.

Strategic Approach
- ● top down approach or command and control approach
- ● bottom-up approach or participatory/voluntary approach

(1) Spatial Approach

On spatial consideration environmental management may be approached at three levels viz. (ii) at local level, (ii) at regional level, and (iii) at national or international level as regards the spatial dimension, and the management strategies may be chalked out on the basis of needs, aspirations, perceptions, priorities and inhibitions of the individuals, society and the government. For example, the problem of ozone depletion and its probable consequences have, no doubt, become an environmental issue of global concern but there is difference in the outlook between the western developed world and developing world regarding the control of ozone depletion. The western developed countries are giving top priorities to tackle the problem of ozone depletion caused by the release of chlorofluorocarbons and halogen gases because they are going to be immediate victims of increased ultra-violet solar radiation and increased incidence of skin cancer whereas the developing countries are reluctant to stop the production and consumption of ozone depleting substances (chlorofluorocarbons-CFCs) because they believe that by doing so they will remain undeveloped and will be deprived of modern amenities which the western developed countries are enjoying since long.

Similarly, global warming and climate change have become most serious environmental problems of the 21st century and most of the countries, including both developed and developing countries, have agreed to reduce the emission of greenhouse gases mainly carbon dioxide under Kyoto protocol but a few nations, such as the USA and Australia, are not agreeable to the theory of global warming and consequent climate change.

The environmental managers whether at local, regional, national or international levels, should always keep this fact in mind that the earthly resources are finite and the environmental system is a closed system. It is, thus, necessary to keep the whole world in mind while attempting environmental planning at any level. Secondly, the environment is a natural gift and thus is a public property to be shared by all 'types of life (plants and animals) in the biosphere. Thus, one should consider the welfare of all kinds of living things in the biospheric ecosystem while attempting for the utilization of natural resources and environmental management. In other words, 'since environment belongs to man and all living organisms its planning should involve entire biological word'. Individualistic approach to environment and its utilization should be discouraged because this approach does not pay any attention to the conservation of environmental resources as one has a tendency to acquire more than one's normal share from the nature. Efforts should be made to create such situation which may make individual responsible to a group, community or society for his activities towards the uses and misuses of environmental resources. 'The environmental planning, therefore, begins from individual or home and is best medium for achieving social justice, equitable distribution of economic wealth and uniform regional development' (L.R. Singht, et. al., 1983).

2. Ecological Approach

As regards methodological consideration there are two approaches to environmental management which are collectively known as ecological approach.

(1) conservation approach, and

(2) preservation approach.

(1) **Conservation approach :** advocates for adjustment with physico-biotic environment in terms of technological and behavioural institutional adjustments. In other words, the environmental (natural) resources may be utilized for the socio-economic development of human society but simultaneously efforts should also be made to maintain ecological balance, ecosystem stability and environmental quality as far as possible by adopting suitable pollution-safe and eco-friendly technologies and by making the society answerable to any maladjustment in the natural ecosystem. The conservation approach to environmental management is based on the following two pespectives and goals :

Perspectives
- to restrict and minimise adverse effects of human activities during exploitation and utilization of natural resources on environment
- to optimise the productivity of natural environmental ecosystems

Basic aims
- to ensure the preservation of environmental quality → that has
  - aesthetic value
  - recreational value
  - economic value
  - ecological value
- to ensure a continuous yield of plants, animals and materials → by
  - balanced cycle of harvest
  - renewal of resources

It is apparent that conservation approach of environmental management aims at achieving the goals of sustainable environment, sustainable development and sustainable society. The natural resources should be used for development purposes in such a way that there is continuous supply of natural resources and there is no damage to environment. Thus, recycling and regeneration of renewable natural resources are the fundamental bases of conservation approach of environmental management. In fact, this approach in basically **ecocentric approach** based on **gaia hypothesis.**

(2) **Preservation approach :** to environmental management advocates non-interference of man with nature or say with physico-biotic environment and complete adaptation of man to natural environment. This preservative approach is, in fact, not practicable because non-interference with natural environment would lead the humanity to complete starvation and even extinction. If man has to survive he must derive some thing from the nature, and even the exploitation of minimum resources from the natural environment to fulfill the basic needs of human society would cause disequilibrium of some sort in the ecological balance and ecosystem stability resulting into environmental degradation and pollution.

Recently, the scope of preservation approach has been limited to the preservation of ecologically significant plants and animals in specially demarcated and well protected areas where endangered, threatened and potential extinct species (which may become extinct, if not protected) of plants and animals are protected from the invasion of man and other animals. Such habitats or areas are variously called such as nature reserve or biosphere reserve, national parks, bird sanctuaries etc.. Even a single species of animals is given full protection in specifically demarcated habittats such as (in India) 'project tiger', 'project elephants', 'project rhinos' etc.

3. Environmental Management System (EMS) Approach

There are two types of environmental management system approaches as follows :

(1) Command and control approach or top-down approach

(2) Participatory or hands off voluntary approach or bottom-up approach.

(1) **Command and control approach** of environmental management is, in fact, government controlled approach wherein government machinery works in descending hierarchical orders e.g. central government→state govt.→district administration→block officials→gram panchayat (in Indian perspective). Such approach is basically anthropocentric approach known as **top-down approach.** It is insensitive, technocratic, compartmentalized and authoritarian, centralized, non-sustainable and is based on command and coercion i.e. forceful implementation of development plans not caring for needs and aspirations of large section of society to be adversely affected such as formulation and implementation of large dams projects e.g. Tehri Dam Project, Sardar Sarovar Project. These projects were launched (and now are complete) without the involvement of local population.

(2) **Participatory approach,** is also known as ecocentric and **bottom-up approach** of environmental management. This is a hands-of voluntary and reward-based approach and is ecocentric, decentralized, appropriate (because it uses eco-friendly

technology), participatory, and sustainable approach. This approach involves community participation, NGOs, social groups and governments.

Methods

Basically, there are two types of methods of environmental management i.e. holistic method and monistic method. **Holistic method** involves the solution of all environmental problems of a region, whereas **monistic method** seeks solution of single problem at a time. System modelling is generally applied to implement a certain development project for the utilization and conservation of natural resources.

J.N.R. Jeffers (1973) has formulated the following **five-stage iterative planning process** for land use and natural resource management.

Table 23.1 : Five stage iterative planning process based on system modelling

Stage	Action
1.	Indentify and agree goals and objectives
2.	Initiate research leading to proper understanding of the relevant issues
3.	Identify and evaluate alternative strategies for achieveing the objectives
4.	Select and implement a particular strategy
5.	Monitor the results; possibly modify the plan in the light of changing demands and values

Source : J.N. R.Jeffers, 1973; System modelling and analysis in resource management, Journal of Environmental Management, Vol. 1.

23.2 ECOLOGICAL BASIS OF ENVIRONMENTAL MANAGEMENT

Here environmental management is taken to manage the ecological resources based on ecological principles. Any environmental planning and management whether at local, regional, national or international level (involving the whole atmosphere and the hydrosphere) must be based on fundamental ecological principles if we are interested in the survival of human beings and if we do not want to be cursed by our future generations and thus the stability of the biosphere in general and survival and stability of individual ecosystems in particular should be maintained.

Ecological basis of environmental management is, in fact, based on ecocentric approach to the management of ecological resources, leading to the attainment of sustainable environment, sustainable development and sustainable society through rational exploitation and optimal utilization of natural resources, both abiotic (mainly minerals and soils) and biotic (plants and animals) resources. Both the approaches of environmental management (which are ecocentric), conservation and preservation approaches (as discussed above), form the core of ecological basis of environmental management.

The following fundamental ecological issues should be considered before attempting management of ecological resources.

- ➤ components and dynamics (energy flow and circulation of matter in the ecosystem, see chapters 8 and 9) of biospheric ecosystem,
- ➤ form, function and stability of natural ecosystem (chapter 5),
- ➤ ecological changes through time (evolution of plants and animals in historical perspective, chapters 10 and 11) and space (dispersal and distribution of plants and animals, chapters 10 and 11),
- ➤ exploitation and utilization of ecological resources, and
- ➤ impacts of human activities on natural environment leading to environmental degradation and pollution (chapters 20 and 21).

The fundamental ecological principles govern various aspects of natural ecosystems and organisms therein such as (i) evolution, dispersal and distribution of plants and animals; (ii) extinction of species; (iii) biological succession; (iv) transfer, circulation and consumption of matter and energy in the different components of natural ecosystems; (iv) cycling and recycling of organic and inorganic substances in the natural ecosystems through biogeochemical cycles; (vi) stability and instability of ecosystems; (vii) life cycles of organisms, and (viii) interrelationships among organisms, and between organisms and physical components of the environment.

Ecological basis of environmental management includes the following aspects :

1. meaning and classification of ecological resources,
2. ecological principles which govern ecological resources,
3. survey of ecological resources,
4. evaluation of ecological resources,
5. approaches to the management of ecological resources, and
6. conservation and preservation of ecological resources.

Ecological Principles

The following basic ecological principles must be taken into consideration before formulating and implementing any environmental management strategy mainly resource management :

- Biotic and abiotic components of biospheric ecosystem and subsequent smaller ecosystems are interconnected and closely interrelated to large-scale biogeochemical cycles.
- Sustained life on the earth is a characteristic features of biospheric ecosystem.
- Nothing actually disappears when we throw them away as wastes after use.
- All the systems and environmental/ecological problems are ultimately interrelated and so we should not solve environmental problems one by one (monistic approach) but should seek solutions together (holistic approach).
- Nature has spent millions of years to create resources and in making stable ecosystem and maintaining ecological balance as geological processes, which make mineral resources, operate very slowly.
- Natural resources of planet earth are finite and belong to all biota including man. In fact, natural resources are public property, and hence no one, whether individual or a community or a nation, is authorized to misuse them.
- All living organisms and physical environment are mutually reactive.
- Energy flow in the ecosystem is unidirectional and is governed by the first and second laws of thermodynamics.
- Circulation of matter in the natural ecosystem is cyclic in nature and is governed by cyclic pathways of biogeochemical cycles.
- Ecosystems productivity depends upon availability of solar energy and the efficiency of plants to convert solar energy into chemical energy.
- Ecosystem stability is controlled by the richness of biological communities, both plants and animals, which (richness) is itself governed by biodiversity. The greater is the biodiversity, the greater is the stability of natural ecosystem and vice versa. The ecosystem and ecological balance is also governed by the principle of **'homeostatic mechanism'** and **'gaia hypothesis'.**
- Rational exploitation and optimal utilization of natural resources and proportionate regeneration of renewable resources make the natural environment sustainable and maintain ecological balance.

Ecological Resources

The meaning and classification of ecological resources have been given in the preceding (22nd) chapter. Ecological resources comprise all biotic resources i.e. floral and faunal resources. Ecological resources are generally divided into (1) floral resources (plant resources), and (2) faunal (animals) resources, but more specifically these are divided into (1) natural ecological resources i.e. wildlife (both plants and animals), and (2) managed ecological resources, such as agricultural crops, planted trees, bushes and shrubs.

Survey of Ecological Resources

The first step in the management of ecological resources of any country or a region is to make an exhaustive survey of all of the existing ecological resources including plant and animal species so that an elaborate inventory of all the ecological resources may be prepared. Thus, the mass data base of ecological resources collected through extensive survey by using field survey methods as well as remote sensing techniques would help in their classification. It may be pointed out that till now there is no common and standardized methodology for the survey of ecological resources which may be applicable to all countries and regions. Instead, local and individual surveys of ecological resources have been done in various parts of the world based on different methods and techniques. Thus, the inventories and data of ecological resources derived through local individual methodologies are not comparable. It is, therefore, the first requirement for the survey and preparation of inventories of ecological resources for their proper evaluation and management to choose proper technique and method of survey.

It may be mentioned that the survey of vegetation is to some extent easier and simpler but the survey of animals is difficult because of their mobility. Survey may be based on mapping by remote sensing and GIS (geographic information system), by GPS (ground positioning system), aerial survey, and limited field survey. The mass dataset derived through appropriate survey methods are classified into different categories following proper taxonomic methods. Lastly, a detailed inventory of ecological resources of a region or a country is prepared on the basis of categorization of resources.

Among the standardized methodologies of survey, classification and preparation of inventories of ecological resources the following are more important :

(1) user-oriented classification of woodland ecosystem by R.G.H. Bunce and M.W. Shaw, and

(2) needle sortcard inventory system by W. Ault-father and E.S. Crozier, for documenting physical inventory of wildlife resources and appropriate management strategies for different areas.

Another teething problem of the survey and inventory of ecological resources is the variation of bases for the classification of ecological resources adopted in various inventory schemes and therefore there is problem of the comparison of data of ecological resources. For example, two standardized schemes of vegetation classifications by two standardized organizations differ substantially as follows :

(1) Method of classification of vegetation adopted by International Biological Programme (IBP) is based on (a) the spacing of plants, and (b their **lifeforms.**

(2) Method of vegetation classification use by the UNESCO is based on function, structure an habitat characteristics of vegetation.

In some of the countries vegetation classified on the basis of nature of conservation suc as in India vegetations, mainly forests, are divide into reserved forests, protected forests, degrade forests etc.

Evaluation of Ecological Resources

Evaluation of ecological resources is based o value judgement of habitats as well as species plants and animals of a region having individual complex habitats. Thus, evaluation of habitats an ecological resources largely help in assessing th suitability of an area for different uses and formulating management programmes and conse vation strategies. Various criteria and approach are adopted for the evaluation of ecological r sources as follows :

- **Ranking method** : Evaluation of ecologic resources on the basis of ranking of ecolog cal value of sites on the basis of degree human interference.

  M.E. Pickering, 197

- **Regional evaluation method** : Specific gional evaluation of ecological resources the basis of vegetational criteria (such spacing of trees, form, function and str ture).

  R.A. Hawes and R.J. Hudson, 19

- **Conservation value method** : Ranking ecological resources on the basis of th conservation values in protected areas.
- **Economic value method** : Ranking of ecolo cal resources on the basis of their econo values as suggested by D.R. Helliwell (19 but F.B. Goldsmith (1975) contradicted scheme and maintained that 'it is prefer to compare areas in terms of their plant animal species richness and diversity, as as habitat diversity, so that they can ranked in order. It is impractical to place kind of monetary values on either end, or

point, of the scale as they are affected by so many other extrinsic factors'.

- **Landscape evaluation method :** Evaluation of ecological resources together with the evaluation of land use capability and landscape attractiveness.

  J.S. Bibby and D. Mackney, 1969

  R.S. Crofts and R.V. Cooke, 1974

- **Nature conservation value method :** Evaluation of ecological resources on the basis of 'nature conservation value of various kinds of habitats' adopted by Nature Conservancy Council (NCC) of U.K. The London-based NCC has presented a list of ranked habitats on the basis of nature conservation value of habitats (table 23.2).

Table 23.2 : Nature conservation value of various habitats (of Scotland, U.K.)

Category I	Most Important habitats for Wildlife	
	Primary woodlands, High mountain tops	lowland heaths, unpolluted and untreated rivers, lakes, canals, permanent dykes, large marshes and bogs
	Permanent pastures and meadows untreated with fertilizers or herbicides	coastal habitats such as cliffs, dunes, salt marsh etc.
Category II	Moderately Important Habitats for Wildlife	
	Broad-leaved plantations	mature conifer planations
	Recently planted confier planations	copses, corner plantation etc.
	Morrland and rough grazing	hedges
	Farm ponds	gravel pits, clay pits
	Road and railway verges, arable land with rich weed flora	small marshes and bogs, disused quarries, neglected orchards
	Large gardens	golf courses
Category III	Little Important Habitats for Wildlife	
	Conifer plantation with no ground cover	derelict land in towns, polluted water of all kinds
	Temporary water bodies	grass leys
	Improved pastures	playing fields
	Airports	small gardens
	Allotments	arable land with poor weed flora
	Horticultural crops and commercial orchards	Industrial and urban land

Source : Nature Conservancy Council, 1977 : Nature Conservation and Agriculture. (in C.C. Park, 1980).

C.C. Park (1980) has grouped all the available approaches to ecological evaluation into the following four categories :

- approach based on the **evaluation of individual species** wherein evaluation is generally based on the degree of uniqueness of species.
- approach based on the evaluation of ecological zones within an area wherein evaluation is generally based on ecological diversity.
- approach based on the **evaluation of habitats** wherein evaluation is based on the characteristics of individual species.

- approach based on the **evaluation of habitats and ecological zones** wherein evaluation is based on vegetation and other criteria simultaneously.

These four approaches to the evaluation of ecological resources may be summarized as follows :

(1) individual species approach,
(2) ecological zone approach,
(3) habitat approach, and
(4) composite approach

A few of the methods of the evaluation of ecological resources are given below :

(1) **Individual Species Method :** This method lays emphasis on calculation of significance of a single species of plants and animals which needs conservation or preservation (complete protection) in a specific habitat. It may be mentioned that different criteria may be adopted for evaluation of conservation significance in different locations having varying environmental conditions. A **threat value method** has been developed by the Biological Record Center of Nature Conservancy Council (BRCNCC) of U.K. wherein the rare plant species are classified on the basis of threat to their survival. The elaborate scheme of calculating 'threat value' for individual species in a single or multiple habitats (sites) has been presented in table 23.3.

Table 23.3 : Method of calculation of threat value for individual plant species

Step : 1 Derive values for each of the following characteristics of the study species :

(a) The rate of decline of that species over a decade of observation :

0 : decline less than 33%
1 : decline between 33 and 66%
2 : decline over 66%

(b) The number of localities of the species known to the Biological Record Centre (BRC) :

0 : over 16 sites
1 : 10-15 sites
2 : 6 - 9 sites
3 : 3 - 5 sites
4 : 1 - 2 sites

(c) A subjective assessment of the attractiveness of the species (a measure of the likelihood of it being picked):

0 : not attractive
1 : moderately attractive
2 : highly attractive

(d) The 'Conservation Index' for the species-an arbitrary figure related to the % of the localities of that species which are in nature reserves :

0 : over 66% in nature reserves
1 : 33 - 66%
2 : less than 33%
3 : less than 33% and these sites are subject to exceptional threat

(e) The remoteness (relative ease with which the species could be reached by the public) :

0 : not easily reached
1 : moderately easily reached
2 : easily reached

(f) Accessibility (ease of access once the site has been reached) :

Scoring as done in step e

Step 2 : Calculate the threat number (TN) for the species from the given formula viz.

threat number (TN) = (a+b+c+d+e+f)

The maximum 'Threat Number' possible is 15, and the observed range is 2-13.

Source : F.H. Perring and L. Farrell, 1977 : British Red Data Books, 1. Vascular Plants (Society for the Promotion of Nature Conservation, London) (in C.C. Park, 1980).

On the basis of threat value number (15) the concerned plant species may be divided into 3 broad threat categories :

(i) 0-5	minimum threatened species, and hence needs no immediate protection.
(ii) 6-10	moderately threatened species, needs conservation in nature reserves.
(iii) 11-15	highly threatened species, needs preservation in well protected areas.

(2) **Ecological Zone Method** : This method involves the evaluation of different ecological zones on the basis of ecological diversity. This method is based on the connotation that the ecological zone with large biodiversity needs no immediate conservation but the ecological zone with poor ecological diversity needs high level of conservation and protection.

C.R. Tubbs and J.W. Blackwood (1971) have maintained that 'the conservationist must devise a means of evaluating the relative floristic and faunistic values of land, and of presenting this means in a form which is easily interpretable by planners, and at the same time is easily comparable with other information'. The scheme of evaluation of ecological resources of C.R. Tubbs and J.W. Blackwood involves the following steps :

- sub-division of an area (a region) under study into first order ecological zone, which is named as Primary Ecological Zone (PEZ),
- derive ecological evaluation value for each primary ecological zone based on general land use and ecological diversity of the concerned habitat, and
- prepare a final relative ecological evaluation map (REEM). The ecological evaluation map should also contain the following :
  (i) definition of boundaries of each REEM,
  (ii) relative value of each zone,
  (iii) written statements about the characteristics of each zone, and
  (iv) desirable conservation practice, meaning thereby what type of conservation method should be adopted.

Table 23.4 presents a summary of the ecological zone method of C.R.Tubbs and Blackwood for the evaluation of ecological resources.

Table 23.4 : Ecological zone method of ecological evaluation by C. R. Tubbs and J. W. Blackwood.

STEP 1 : Sub-divide the study area in primary ecological zones (PEZ)

ZONE 1 : unknown vegetation (including non-plantation woodland)

ZONE 2 : plantation woodland

ZONE 3 : agricultural land

STEP 2 : Evaluate the ecological value of each zone, using three main concepts :

(a) unknown or semi-natural habitats have limited distribution in lowland Britain, and are subject to pressure from reclamation and development (and thus they have conservation value).

(b) areas of plantation woodland often form valuable wildlife reservoirs (thus they too have a relatively high conservation value).

(c) ecological interest in agricultural land will vary inversely with the intensity of agricultural land.

Thus the ecological evaluation for the three zones are :

Ecological Evaluation

ZONE 1 : Category I or II (the final decision rests on subjective estimate of rarity of habitat type and presence of features of outstanding scientific importance)

ZONE 2 : Category II or III (based on subjective estimation of the value of the habitat as a wildlife reservoir)

ZONE 3 : Relative value is a function of habitat diversity :

(a) This is related to the presence of definable features :

(1) permanent grassland

(2) hedgerows and hedgerow timber

(3) boundary banks, roadside cuttings and banks, verges

(4) park timbers and orchards (other than those in commercial production)

(5) ponds, ditches, streams, and other water courses

(6) fragments of other unsown vegetation (including woodland) smaller than 0.5 km^2

(b) Score for the presence of each group of features :

0 = none/virtually none in the zone

1 = present (but not a conspicuous feature)

2 = numerous (conspicous feature)

3 = abundant

(c) Evaluation of the value for the zone (based on sum of scores for individual features present in the zone) :

Total score	Category
15-18	II
11-14	III
6-10	IV
0-5	V

Source :C.R. Tubbs and J.W. Blackwood, 1971 : Ecological evaluation of land for planning purposes, Ecological Conservation, Vol 3. pp. 169-72. (in C.C. Park, 1980).

(3) **Conservation Course Method** : F.B. Goldsmith presented a scheme of conservation course method of determining ecological value in 1975 on the basis of objective assessment of habitat area, scarcity and number of species present, and vegetation structure by using **grid square method.** The assessment is ultimately used to produce a numerical index of ecological value as given in table 23.5.

Table 23.5 : Goldsmith's grid square method of determinng ecological value.

STEP 1 : Divide the whole study area into 'distinct land system' :

System 1 : unenclosed upland (mostly morrland over 300 m)

system 2 : enclosed cultivated land (mostly permanent pasture)

System 3 : enclosed flat land (mostly arable land in valley bottoms)

STEP 2 : Record the distribution of habitats within each land system :

- (a) arable and ley
- (b) parment pasture
- (c) rough grazing
- (d) woodland
  - (i) deciduous and mixed
  - (ii) coniferous
  - (iii) scrub
  - (iv) orchard
- (e) hedges and hedgerows
- (f) streams etc.

STEP 3 : Determine the following parameters for each habitat (on the basis of individual km grid squares) :

(i) **Extent** (E) : for habitats a to b (as referred to above) in hectare (ha), for linear features (as hedges and streams) is length in km/km^2

(ii) **Rarity** (R) : R = 100% area per land system

(iii) **Plant species richness** (S) : the number of species of flowering plants recorded in sample plots (20 m × 20 m grids) in each habitat type in each land system

(iv) **Animal species richness** (V) : this correlates with vegetation stratification, thus V = the number of vertical layers in the vegetation (grassland V = 1, well developed woodland V = 4, maximum strata or layers in the forests are 4)

STEP 4 : Determine the Index of Ecological Value (IEV) for each grid square, based on the following formula.

$$IEV = \sum_{N}^{i=1} (E \times R \times S \times V)$$

(Index of Ecological Value is the sum of the product of aforesaid four indices)

STEP 5 : Standardize the IEV values to a range of 1-20, then plot the standardized values in map form, on the grid square basis.

Source : F.B. Goldsmith, 1975 : The evaluation of ecological resources in the countryside for conservation purposes, Biological Conservation, Vol. 8, pp. 89-96., in C.C. Park, 1980.

Some more methods and techniques of the evaluation of ecological resources have been developed based on regional studies. For examples, (i) 'Indicator Species' Woodland Evaluation Scheme of G.F. Peterken et al. (1974); (ii) Ecological Evaluaiton Scheme of G.D. Watts et al. (1975); (iii) Weighted Value Approach of F.R. Gehlbach (1975) etc. All these methods of ecological evaluation differ significantly from each other because they are based on different criteria. It may be pointed out that common standardized method of the evaluation of ecological resources applicable to all of the ecosystems world over may not be possible because there are wide range of variations in the natural habitats and environmental conditions throughout the world. Even one method of ecological evaluation may not be applicable to a large country such as the USA, Russia, China etc. Little attempt has been made to develop methodologies to evaluate ecological resources in India. All of the aforesaid models are based on British experiences and they cannot be applied in Indian case.

Preservation and Conservation of Ecological Resources

Generally, people use the terms preservation and conservation as synonyms but both the terms differ significantly in their meaning and application. In ecological context preservation means upkeep of rare and endangered species of plants and animals in specially protected areas so that their populations may increase to optimum level. No use of such resources is permitted. On the other hand, conservation is a process which aims at proper use, preservation and management of natural resources in such a way that they are always available in desired quantity and quality for judicious use by humans as well as the ecological balance and environmental quantity is maintained leading towards the attainment of sustainable environment, sustainable development and sustainable society. Thus, conservation is defined as follows :

Conservation is "the establishment and observation of economically, socially and politically acceptable norms, standards, patterns or models of behaviour in the use of natural resources by a given society". ,R. Beazley, 1967

In fact, conservation is applied ecology wherein basic ecological principles are applied in the gainful utilization and conservation of natural resources in general and ecological resources in particular.

According to E.P. Odum (1971) a conservationist has the following two aims before him :

- to ensure the preservation of a quality environment that has aesthetic, recreational, and economic value, and
- to ensure a continuous yield of useful plants, animals and materials by establishing a balanced cycle of harvest and renewal of resources.

The need for conservation arises from the fact that urbanization, industrial expansion, large-scale land use changes mainly due to expansion in agricultural areas at the cost of forest areas, environmental degradation and pollution arising out of rapid rate of rapacious exploitation of natural resources and modern production processes and advanced technologies have threatened the stability and even survival of natural ecosystems and existence of several plant and animal species.

The ecologically significant plant and animal species meant for preservation and conservation are divided into the following 3 categories :

(1) endangered species,

(2) threatened species, and

(3) extinct species.

F.H., Perring and L. Farrell (1977) have enlisted 321 species of flowering plants as being rare (161 species), vulnerable (95 species), endangered (46 species) and extinct (19 species). IUCNNR (International Union for the Conservation of Nature and Natural Resources) has constituted a 'Threatened Plants Committee' to devise ways and means for the protection and conservation of 2000 species of flowering plants which are now threatened species.

The conservation and preservation of ecological resources may include the following measures :

- provision for **nature (biosphere) reserves,**
- establishment of national parks and sanctuaries,
- establishment of protected areas for endangered species such as Project Tiger, Project Rhino, Project Elephants etc. schemes in India.
- formulation, enactment and forcefully execution of environmental and wildlife acts laws,
- habitat improvement programmes,
- effective means of census operation to have regular measurement of population size of endangered species,
- provision for large-scale drive for treatment of animals during epidemics,
- establishment of research and monitoring centers to study the biological behaviour of wild animals by using electronic devices,
- provision for elementary environmental education to general public about the environmental values of ecological resources, etc.

The conservation of ecological resources may be approached in the following 3 ways :

(1) through species preservation/species approach,

(2) through assemblage protection (all species of a region), and

(3) through habitat protection and preservation.

(1) **Species Preservation :** Species preservation involves identification, demarcation and enlisting of individual endangered species of plants and animals, and reservation of a particular habitat for full

protection of endangered and rare single species from outside invasion either from animals or from man. Such protected natural habitats are also called as **'nature reserve'**. It is a matter of satisfaction that many countries are now seized of the problem of the preservation and protection of rare and endangered species and have established nature reserves for the purpose. For example, gray seals are protected in the sanctuary of France Islands off the coast of Northumberland, U.K.; Wood Buffalo National Park (Canada) preserves North American bison in the northern Alberta and North-West Territories of Canada; frigate birds are protected in small islands in Sabah, Malaysia; Javan rhinos are preserved in Udjung Kulon-Panailan (western Java); Gir lions are protected in Gir forests of Gujarat in India etc.

(2) **Assemblage Protection :** Assemblage protection involves protection and preservation of several species of plants or animals together in the same habitat having uniform environmental conditions. The environmental conditions and habitat characteristics are such that large numbers of animals mainly migratory birds are attracted from many parts of the world. Many countries have established such sanctuaries for providing unpolluted fresh environmental conditions to the animals. For example, the wildfowl refuges of the USA provide shelters and ideal places for nesting for many species of ducks, geese and waders; Delhi zoo and Bharatpur bird sanctuary (India) provide ideal habitats for migratory birds where maximum cover and food supply are assured for the migratory birds which come from remote areas of the world such as from Siberia and the birds are completely protected from hunting or from any human actions; high mountain reserves in the USA protect several alpine plant species and so on.

(3) **Habitat Protection :** Habitat protection means reservation of large areas having diverse ecological resources for the purpose of overall protection of natural ecosystems and ecological resources therein. Such 'nature reserves' are called as **national parks**. Such national parks are fully protected from outside encroachment either by animals or man to serve as 'museum of nature'. Almost every country has developed national parks. The concept of **'biosphere reserve'** was initiated in 1968 under the Man and Biosphere programme (MAB) of the UNESCO (of UNO) for full protection of abiotic and biotic components of a large habitat.

The **'biosphere reserve'** will be discussed in the succeeding (24th) chapter of this book entitled 'biodiversity, biosphere reserve and wildlife management'.

Though **'environmental impact assessment'** is an integral part of environmental management but it is being discussed here in separate section.

23.3 ENVIRONMENTAL IMPACT ASSESSMENT

Meaning and Concept

At the very outset it is desirable to define 3 basic terms used in the science of environmental impact assessment, namely environmental impact statement, environmental impact and environmental impact assessment.

Environmental impact : The probable effects of human activities regarding the use of environmental/natural resources on natural environment is called environmental impact.

Environmental statements : General statements on the likely impacts of human activities, mainly economic, during the launching of development projects, exploitation and processing of natural resources on natural environment are called environmental impact statements (EIS).

Environmental impact assessment (EIA) : The assessment and evaluation of environmental effects of human activities of environmental effects of human activities during exploitation and processing of natural resources are called environmental impact assessment. In fact, environmental impact assessment includes both likely adverse impacts of human activities during the execution and progress of development projects, such as harnessing of river water for irrigation and generation of hydel power, exploration, and drilling for fossil fuel, establishment of industries of various sorts, land use changes etc., and after the completion of project and its operation on natural environment. Environmental impact assessment also includes environmental impact statements.

Thus Environmental Impact Assessment (EIA) and Environmental Impact Statement (EIS) 'refer to the studies and statement which firstly attempt to produce estimates of future environmental changes attributable to a proposed action, and secondly attempt to suggest the likely impact of these changes (environmental changes to be brought in by human actions) on man's future well-being' (K.J. Gregory and D.E. Walling, 1981). Thus environmental impact assessment is a method of evaluating environmental consequences i.e. environmental changes which are likely to be caused by the proposed human activities related to land use changes; construction of dams, reservoirs, roads, rails, bridges etc.; industrial location; urban expansion etc. and the possible adverse effects of these environmental changes (environmental degradation and pollution resulting into ecological imbalance and ecosystem disequilibrium).

Methods of Environmental Impact Assessment

The genesis of the concept and methods of environmental impact assessment has its root in the enactment of National Environmental Policy Act (NEPA) in the year 1969 with the following major aims and objectives in the USA :

- ➤ to declare a national policy to encourage productive and enjoyable harmony between man and environment.
- ➤ to promote efforts to prevent or eliminate damage to the environment and the biosphere and stimulate the health and welfare of man.
- ➤ to increase understanding of ecological system and nature resources important to the nation.
- ➤ to establish a Council on Environmental Quality (CEQ).

The legislation of NEPA made it obligatory to all of the Federal Agencies (USA) to produce environmental impact assessment for all future major actions for the approval of their development projects. No approval would be given to any proposed development planning and projects without the environmental impact assessments and statements. The NEPA envisages to 'identify and develop methods and procedures which will ensure that presently unqualified environmental amenities and values are given appropriate considerations'. The fundamental steps of environmental impact assessment of NEPA (USA) are given below :

Major Steps (1969)

1. Describe the present environment (the baseline conditions).
2. Describe the project, including purposes and needs.
3. Describe the effects of the project.
4. Describe the impacts, both sort-term and long-term.
5. Suggest and compare alternatives (projects).
6. Provide a projection of the future of the site with and without the project.
7. Suggest mitigating (remedial measures) activities.

The Council on Environmental Quality (CEQ) of the United States revised the major components of environmental impact assessment and statement in 1979 as given below :

Revised Steps (1979) :

1. A statement of purpose and need for the project.

2. A rigorous comparison of the reasonable alternatives.

3. A succinct description of the environment of the area to be affected by the proposed project.

4. A discussion of the environmental consequences of the proposed project and its alternatives. This discussion must include direct and indirect effects; energy requirements and conservation potential; resource requirements; impacts on urban quality and cultural or historical resources; possible conflicts with state or local land use plan policies and controls; and mitigation (remedial) measures. Mitigations include the actions to reduce adverse environmental impacts of implemented projects such as repair and restoration of the environment, reduction or elimination of impacts and compensation to affected parties.

5. A list of the names and qualifications of the persons primarily responsible for the preparation of environmental impact statement and a list of agencies to which the statement was sent.

6. An index.

Composite Steps

The procedures of Environmental Impact Assessment (EIA) and Environmental Impact Statement (EIS) were widely adopted by Federal Agencies in the U.S.A. The United States Council on

Environmental Control (CEC) received statements on about 7000 actions (projects) by 1975 for consideration and approval. Now most of the American states and cities and several countries like Germany, France, Denmark, Eire etc. have adopted the EIA and EIS procedures as formulated by the US Council on Environmental Control. Several countries including India have now developed their own methods of EIS and EIA and now it has been made mandatory to prefix EIS and EIA with all the proposed projects for approval by the respective governments.

Environmental impact assessment and statement, thus, includes the following considerations :

- presentation of the existing environmental conditions in terms of physical, biological, social and economic conditions of the site of the proposed project or plan before the implementation of proposed plan.
- statements on the possible expected effects of proposed project, if implemented, on the existing environmental conditions.
- statements about those unavoidable adverse effects which may come after the implementation of the project.
- presentation of viable alternative projects to the proposed projects.
- statements on the relationship between local short-term uses of the environment and the maintenance of long-term productivity and stability of the environment.
- evaluation of cost of the project and its probable benefits to the society.
- statements on suitable remedial measures of adverse effects arising out of the project after its implementation.

A few alternative methodologies and procedures for formulating environmental impact assessment and statement have been devised by individuals and scientific research organizations such as 'Principles and Procedures of Environmental Impact Assessment' by SCOPE (Scientific Committee on Problem of Environment) in 1975; Procedures for 'Environmental Impact Assessment' and 'Leopold Matrix for Environmental Impact Assessment' by Luna Leopold and others, 1971 and many more.

Leopold Matrix (1971)

Luna Leopold and associates presented a method for environmental impact assessment in the year 1971 which is popularly known as Leopold Matrix.

The following procedures have been suggested by Luna Leopold and his associates for environmental impact assessment :

Table 23.6 : Procedures for environmental impact assessment

1. Statement of Objectives : definition of the objectives sought by the proposed development (plan),
2. Technical possibilities of achieving the objectives,
3. Proposed actions and alternatives (plans) : for achieving the stated objectives,
4. Reprot on the character of the environment before action begins,
5. Principle of alternative engineering proposals submitted as reports; with analysis of monetary costs and benefits of each engineering alternative,
6. Proposed plan (engineering report) and the report on the present environment are considered; this allows evaluation of the likely environmental impact of the proposal. Impacts are evaluated for each major alternative plan. Attention centres on
   (a) magnitude of the impact (scale), and
   (b) importance of the impact (significance)
7. Assessment of environmental impacts of each alternative plan of action, and
8. Environmental Impact Statement is produced; this summarizes the whole analysis, and lists final recommendations and the relative merits of each of the main alternatives.

Source : L.B. Leopold et al 1971 : A Procedure for Evaluating Environmental Impact, United States Geological Survey, Circular 645.

Leopold et al. (1971) have also presented a matrix for the assessment of environmental impacts of proposed plan. This matrix, also known as

Leopold Matrix, involves 100 project actions along the horizontal axis and 88 environmental characteristics and conditions, which are liable to be affected by project actions listed in the horizontal axis, in the vertical axis of the matrix. The following are the variables of project actions and the environmental conditions to be affected by the project actions (table 23.7) :

Table 23.7 : Leopold matrix having environmental characteristics likely to be affected by project actions (part A) and project actions and their impacts (part B).

Part A : Environmental 'characteristics' and 'conditions' likely to be affected by project actions (these variables are arranged vertically in the matrix)

(A) Physical and chemical characteristics
- (1) **Earth**
  - (a) Mineral resources
  - (b) Construction materials
  - (c) Soils
  - (d) Lanform
  - (e) Force fields and background radiation
  - (f) Unique physical features
- (2) **Water**
  - (a) Surface
  - (b) Ocean
  - (c) Underground
  - (d) Quality
  - (e) Temperature
  - (f) Recharge
  - (g) Snow, ice and permafrost
- (3) **Atmosphere**
  - (a) Quality (gases, particulates)
  - (b) Climate (micro, macro)
  - (c) Temperature
- (4) **Processes**
  - (a) Floods
  - (b) Erosion
  - (c) Depostion (sedimentation, precipitation)
  - (d) Solution
  - (e) Sorption (ion exchange, complexing)
  - (f) Compaction and settling
  - (g) Stability (slides, slumps)
  - (h) Stress-strain (earthquake)
  - (i) Air movements

Part B : Project actions (these variables are arranged horizontally in the matrix)

(A) Modification of Regime
- (a) Exotic flora or fauna introduction
- (b) Biological controls
- (c) Modification of habitats
- (d) Alteration of ground cover
- (e) Alteration of groundwater hydrology
- (f) Alteration of drainage
- (g) River control and flow modification
- (h) Canalization
- (i) Irrigation
- (j) Weather modification
- (k) Burning
- (l) Surface or paving
- (m) Noise and vibration

(B) Land Transformation and Construction
- (a) Urbanization
- (b) Industrial sites and buildings
- (c) Airports
- (d) Highways and bridges
- (e) Roads and trails
- (f) Railroads
- (g) Cables and lifts
- (h) Transmission lines, pipe lines and corridors
- (i) Barriers including fencing
- (j) Channel dredging and straightening
- (k) Channel revetments
- (l) Canals
- (m) Dams and impoundments

(B) Biological Condition

- (1) **Flora**
  - (a) Trees
  - (b) Shrubs
  - (c) Grass
  - (d) Crops
  - (e) Microflora
  - (f) Aquatic plants
  - (g) Endangered species
  - (h) Barriers
  - (i) Corridors
- (2) **Fauna**
  - (a) Birds
  - (b) Land animals including reptiles
  - (c) Fish and shellfish
  - (d) Benthic organisms
  - (f) Microfauna
  - (g) Endangered species
  - (h) Barriers
  - (i) Corridors

(C) Cultural Factors

- (1) **Land use**
  - (a) Wilderness and open spaces
  - (b) Wetlands
  - (c) Forestry
  - (d) Grazing
  - (e) Agriculture
  - (f) Residential
  - (g) Commercial
  - (h) Industrial
  - (i) Mining and quarrying
- (2) **Recreation**
  - (a) Hunting
  - (b) Fishing
  - (c) Boating
  - (d) Swimmig
  - (e) Camping and hyking
  - (f) Picknicking
  - (g) Resorts
- (3) **Aesthetic and Human Interest**
  - (a) Scenic views and vistas

- (n) Piers, seawalls, marinas and sea terminals
- (o) Offshore structures
- (p) Recreational structures
- (q) Blasting and drilling
- (r) Cut and fill
- (s) Tunnels and underground structures

(C) Resource Extraction

- (a) Blasting and drilling
- (b) Surface excavation
- (c) Subsurface excavation
- (d) Well drilling and fluid removal
- (e) Dredging
- (f) Clear cutting and other lumbering
- (g) Commercial fishing and hunting

(d) Processing

- (a) Farming
- (b) Ranching and grazing
- (c) Feed lots
- (d) Dairying
- (e) Energy generation
- (f) Mineral processing
- (g) Metallurgical industry
- (h) Chemical industry
- (i) Textile industry
- (j) Automobile and aircraft
- (k) Oil refining
- (l) Food
- (m) Lumbering
- (n) Pulp and paper
- (o) Product storage

(E) Land Alteration

- (a) Erosion control and terracing
- (b) Mine sealing and waste control
- (c) Strip mining, rechabilitation
- (d) Landscaping
- (e) Harbour dredging
- (f) Marshfill and drainage

(F) Resource Renewal

- (a) Reforestation

- (b) Wilderness qualities
- (c) Open space qualities
- (d) Landscape design
- (e) Unique physical features
- (f) Parks and reserves
- (g) Manuments
- (h) Rare and unique species or ecosystems
- (i) Historical or archaeological sites and objects
- (j) Presence of misfits

(4) **Cultural Status**

- (a) Cultural patterns (life style)
- (b) Health and safety
- (c) Employment
- (d) Population density

(5) **Man-made Facilities and Activities**

- (a) Structures
- (b) Transportation network
- (c) Utility networks
- (d) Waste disposal
- (e) Barriers
- (f) Corridors

(6) **Ecological Relationships**

- (a) Salinization of water resources
- (b) Eutrophication
- (c) Disease-insect vectors
- (d) Food chains
- (e) Salinization of surficial material
- (f) Brush encroachment
- (g) Others

Others

- (b) Wildlife stocking and management
- (c) Groundwater recharge
- (d) Fertilization application
- (e) Waste recycling

(G) **Changes in Traffic**

- (a) Railways
- (b) Automobiles
- (c) Trucking
- (d) Shipping
- (e) Aircraft
- (g) Pleasure boating
- (h) Trails
- (i) Cables and lifts
- (j) Communication
- (k) Pipe line

(H) **Waste Emplacement Treatment**

- (a) Ocean dumping
- (b) Landfill
- (c) Emplacement of tailings, spoil and overburden
- (d) Underground storage
- (e) Junk disposal
- (f) Oil well flooding
- (g) Deep well emplacement
- (h) Cooling water discharge
- (i) Municipal waste discharge including spray irrigation
- (j) Liquid effluent discharge
- (k) Stabilization and oxidation ponds
- (l) Septic tanks
- (m) Stack and exhaust emission
- (n) Spent lubricants

(I) **Chemical Treatment**

- (a) Fertilization
- (b) Chemical deicing of highways etc.
- (c) Chemical stabilization of soils
- (d) Weed control
- (e) Insect control (pesticides)

(J) **Accidents**

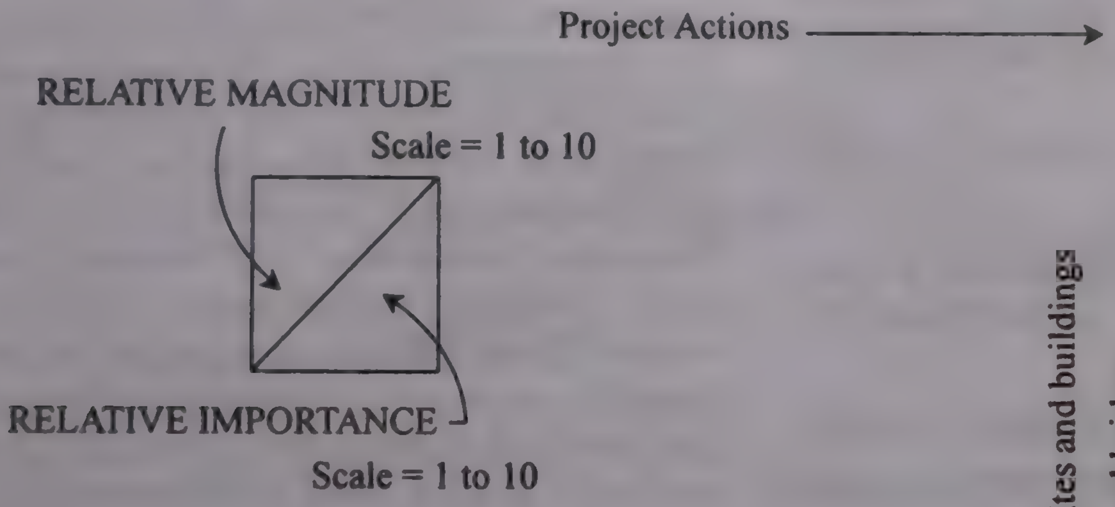
- (a) Explosions
- (b) Spills and leaks
- (c) Operational failures

Others

Source : L.B. Leopold, et al., 1971 : A Procedure for Evaluating Environmental Impact, United States Geological Survey, Circular 645.

Illustration of Leopold Matrix

It may be mentioned that it is not absolutely necessary to include all of the variables as mentioned in table 23.7 for the preparation of environmental impact statements (EIS) and assessment (EIA) while preparying a specific development project action plan. Only those variables are included which are relevant to a specific project and the environmental conditions of the concerned area. Fig. 23.1 illustrates the application of reduced data matrix for a proposed phosphate mining as illustrated by Leopold et. al in 1971. Vertical axis represents the variables of environment of the concerned area, which may be affected by the proposed actions for phosphate mining. The proposed actions have been shown along the horizontal axis (fig. 23.1). Each square (box) of the matrix (fig. 23.1) has two equal halves divided by a diagonal. The upper half of each box denotes relative magnitude of likely impacts having a magnitude scale from 1 to 10 points. The lower half denotes relative importance of the impact of each project action having a 10-point scale running from 1 to 10. The magnitude and importance scores of each box are computed and totalled and a final picture is drawn.



PART B (Table-23.7)

PART A (Table-23.7)

Environmental characteristics and conditions		Industrial sites and buildings	Highways and bridges	Transmission lines	Blasting and drilling	Surface excavation	Mineral processing	Trucking	Emplacement tailings	Spills and leaks
A.2.d	Water quality					2/2	1/1		2/2	1/4
A.3.a.	Atmospheric quality						2/1			
A4.b.	Erosion		2/2			1/1			2/2	
A.4.c.	Deposition Sedimentation		2/2			2/2			2/2	
B.1.b.	Shrubs					1/1				
B.1.c.	Grasses					1/1				
B.2.f.	Aquatic Plants					2/2			2/3	1/4
C.2.c.	Fish					2/2			2/2	1/4
C.2.e.	Camping and hiking					2/4				
C.3.a.	Scenic views and vistas	2/3	2/1	2/3		3/3		2/1	3/3	
C.3.b.	Wilderness qualities	4/4	4/4	2/2	1/1	3/3	2/5	3/5	3/5	
C.4.h.	Rare and unique species		2/5		5/10	2/4	5/10	5/10		
C.4.b.	Health and safety							3/3		

Fig. 23.1 : The reduced data matrix for a phosphate mining Environmental Impact Statement - after L.B. Leopold, et al. 1971.

It may be pointed out that separate matrices are prepared for each alternative proposals or plans. The final Environmental Impact Statement (EIS) includes four information and reports as follows :

- a justification of the proposal,
- description of environmental characteristics and conditions to be affected,
- detailed description of the proposed projects or actions, and
- completed environmental impact statement (EIS)

A latest example of the Sethusamudram Ship Canal Project (SSCP) is given in the next section of this chapter to illustrate the ground reality of EIS and EIA as regards the implementation of a proposed project.

Evaluation of Leopold Matrix

The procedure of Environmental Impact Assessment of Leopold et al. suffers from the following shortcomings :

- It requires a tremendous volume of paper work by requiring detailed reports which obscure the central and important issues.
- Insertion of numerous information and reports makes the scheme confusing and it becomes difficult for the concerned authorities to pick up important but most relevant information.
- It has bias towards physical-biological environment.

The significance of environmental impact assessment of any proposed project or action may be realized through the analysis of case histories of a few projects. In the 1991 edition of this book, when it was published for the first time, 4 development projects namely, (1) Aswan Dam on Nile river, (2) Trans-Alaskan Pipe-line, (3) Sardar Sarovar Project (India), and (4) Tehri High Dam (India) were discussed. By now, these projects are complete (Indian examples). The Tehri Dam Project has now become operational. The Sardar Sarovar Project would become operational soon but many ecological and socio-economic (rehabilitation of outstees, for example) issues and problems have not yet been properly addressed to and solved. These project plans have now been omitted in this edition of 'Environmental Geography' as these have now become outdated. The latest development project aiming at the improvement in India's sea navigation and trade has been launched under the garb of the 'Sethusamudram Ship Canal Project.' It is, thus, desirable to discuss this project to evaluate the positive and negative sides of this project as parts of Environmental Impact Assessment (EIA).

23.4 SETHU SAMUDRAM SHIP CANAL PROJECT

The idea of shipping canal across the 'Thonithurai peninsula' in the sea waters between India and Sri Lanka was conceived by A.D. Taylor of British Navy in the year 1860 but it could not materialize. The project renamed as 'the Sethusamudram Ship Canal Project' (SSCP) was approved in September 2004 by the Govt of India and was launched in July 2006 inspite of stiff resistance from ecologists, local fishermen, politicians, academicians, non-government voluntary organizations (NGOs) etc. on several counts. The primary goal of the project is to make the sea waters of the Gulf of Mannar, the Palk Bay and the Palk Strait between India and Sri Lanka navigable through a sea canal (fig. 23.2).

Salient Features of the Project

The main goal of the project is to connect the Gulf of Mannar to the Bay of Bengal through Palk strait, the Adam's Bridge and the Palk Bay by dredging a ship channel in the shallow part of the sea so that the channel or canal becomes navigable and facilitates the passage of container ships, thus saving much time and fuel as these ships have not to undertake longer route by going around Sri Lanka. The proposed shipping canal will start from Tuticorin harbour and enter the Bay of Bengal via the Gulf of Mannar, the Palk Bay and the Palk strait (fig. 23.2).

The National Environmental Engineering Research Institute (NEERI) was entrusted to (1) find out techno-economic feasibility of the SSCP, and (2) to prepare Environmental Impact Assessment (EIA) report having environmental impact statements (EIS) about SSCP. NEERI submitted its report in 2004 and the same was approved by the Govt. of India in 2004. The **executing body** to execute the project is Sethusamudram Corporation Limited (SCL) while the **nodal agency** is Tuticorin Port Trust (TPT).

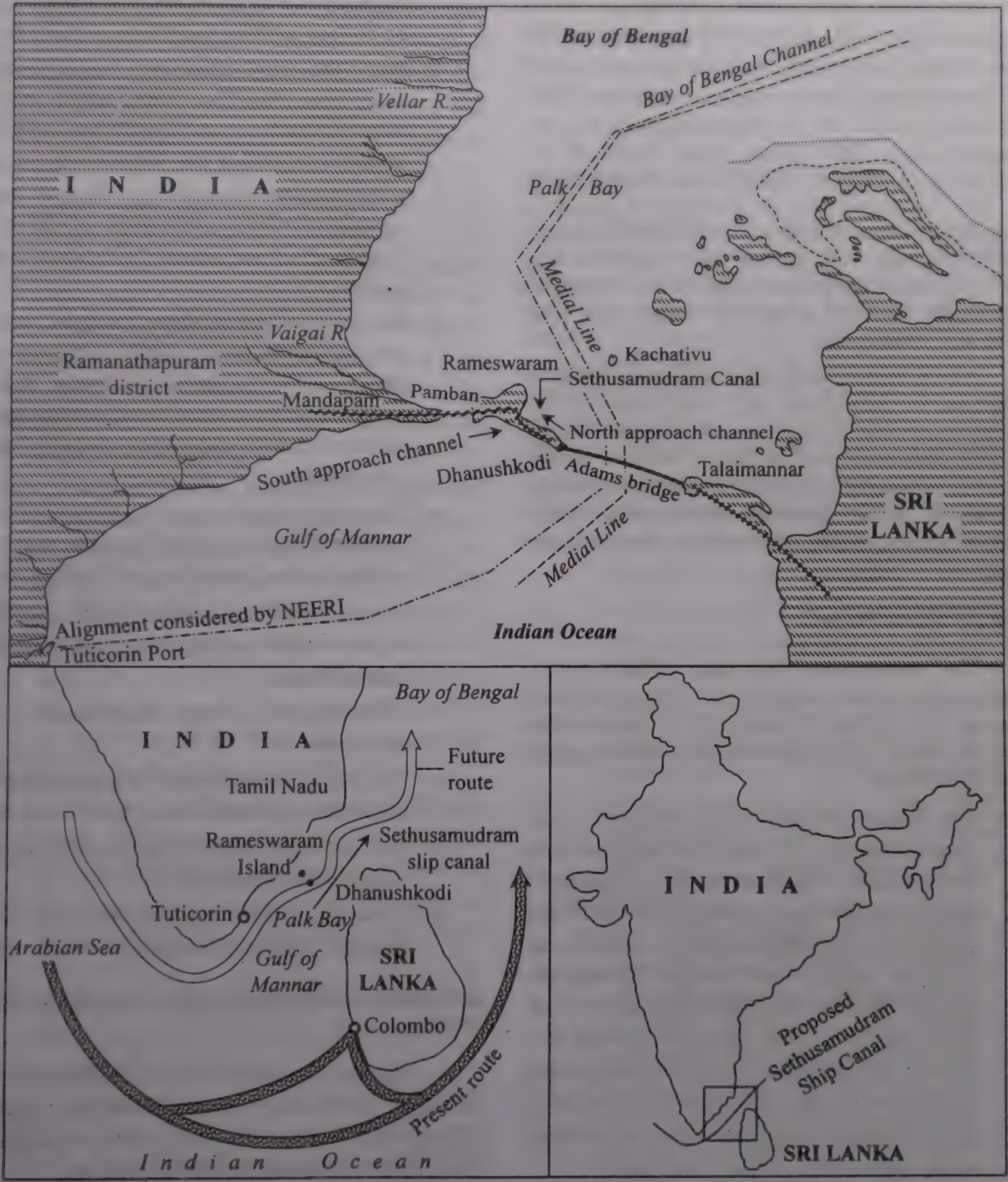

Bay of Bengal
Bay of Bengal Channel
Vellar R.
INDIA
Palk Bay
Medial Line
Vaigai R
Ramanathapuram district
Rameswaram
Kachativu
Sethusamudram Canal
Mandapam
Pamban
North approach channel
South approach channel
Dhanushkodi
Adams bridge
Talaimannar
SRI LANKA
Gulf of Mannar
Medial Line
Alignment considered by NEERI
Tuticorin Port
Indian Ocean
Bay of Bengal
INDIA
Future route
Tamil Nadu
Rameswaram Island
Sethusamudram slip canal
Dhanushkodi
Tuticorin
Palk Bay
Arabian Sea
Gulf of Mannar
SRI LANKA
Colombo
Present route
Indian Ocean
INDIA
Proposed Sethusamudram Ship Canal
SRI LANKA

Fig. 23.2 : Alignment of Sethusamudram Ship Canal. Source :Frontline, 2005.

The total length of the shipping canal would be 152km of which only 74 km would be dredged shipping channel in the Adam's Bridge Area (6 km long and 300 m wide) and the Palk Bay and the Palk Strait (68 km) and the depth of dredged canal would be 12m to enable mother ships or container ships with draught of 10.7m to pass through 152km long shipping canal. This means there would be no dredging in the Gulf of Mannar for a distance of 78 km. The estimated cost of the project, which is designed to be complete by the end of 2008, if started in 2005 (but the dredging operation started in July 2006, and hence the project may not be completed before 2009-10 A.D.), is Rs 2000 crores which may rise to Rs. 3000 crores.

It may be mentioned that the Adam's Bridge is composed of sandstone reef and hence if the basement of sandstones is encountered during dredging operation, the blasting of rocks would be required. According to ecologists powerful blasting of bedrock would generate shockwaves which would drive away fish communities due to sound effects.

Benefits of the Projects

The government officials, TEERI report, Tuticorin Port Trust, and the nodal agencies have presented a long list of benefits which may accrue when the SSCP is completed and becomes operational as follows :

- The ships moving from the harbours of east coast of India to its west coast and from west coast to east coast have to make a round of Sri Lanka but after the completion of SSCP and opening of shipping channel the mother and container ships would navigate through the Gulf of Mannar, the Palk Bay and the Palk Strait and thus there would be saving of a distance of 400 nautrical miles, time saving of 36 hours if navigation speed of ships is maintained at 12 knots per hour, and a saving of Rs. 107 crores on fuel every year.
- There would be no dredging in the Gulf of Mannar and hence there would be no adverse effects on the environment and marine ecosystem and its biological community in this area.
- In Adam's Bridge area having bedrocks of sandstones, dredging would be done for a distance of only 6 km, and hence there would be no loss of flora and fauna in this area.
- Since the canal alignment would be 6 km away from Van Tivu Island which is in the Tuticorin harbour area, and 20 km away from Shingles Island in the Rameshwaram area, and hence there would be no adverse impact on coastal marine organisms of these two islands which are among 21 national marine parks.
- The construction of shore facilities, such as service, jettis, buoy yard, administrative buildings, slipways etc. in the Adam's Bridge area may cause some environmental problems but would greatly benefit trading community,
- The marine environment mainly coral reefs would not be adversely affected by the plying of ships at the annual rate of 2000 ships.
- There would be increase in the export of marine resources from the coastal districts of Tamil Nadu.
- Thermal power plants would receive coal with ease.
- The project would boost industrial development in the southern districts of Tamil Nadu.
- The national defence and security systems would be strengthened.
- Creation of additional fishing lands would benefit fishermen community of the region.

Existing Environmental and Ecological Conditions

The environmental and ecological set up of the Gulf of Mannar and the Palk Bay, forming important closed marine ecosystems are characterized by the following significant features :

- The marine ecosystems of the Gulf of Mannar and the Palk Bay covering an area of 10,500 km^2 are characterized by large biological communities having several species.

- According to NEERI's environmental impact assessment (EIA) and statements report the aforesaid marine ecosystems are biologically very rich and are rated one of the most productive marine ecosystems of the world.
- There is no continuous navigable route for mother ships in India's territorial seawater around its peninsula which may directly connect the ports on the eastern (Kolkata, Paradeep, Visakhapatnum and Chennai) and western coasts (Kandla, Mumbai, Marmagao, Mangalore, Cochine) of India. Presently, the mother/container ships have to navigate around Sri Lanka to connect east and west coasts. This longer sea route takes an additional time of 36 hours and additional distance of 400 km.
- There is a shallow reef ridge composed of sandstones, known as Adam's Bridge, having a depth of 1.5 to 3.0 meters from sea level between Pamban island near Rameshwaram and Talaimanar in Mannar district of Sri Lanka. According to NEERI's report, if the bedrock of sandstones is encountered during dredging operation, blasting of bedrocks would be required. This blasting operation may disturb biological communities.
- There are 3,268 species of flora and fauna in the Gulf of Mannar of which 377 species are rare and endemic to this marine ecosystem.
- The rich corals of the region provide ideal base for biological diversity in this marine ecosystem.
- The Gulf of Mannar is a Marine Biosphere Reserve and its 21 islands have been declared as **marine national parks.**
- The sea grass meadows and sea weeds ecosystems form ideal marine ecosystems which provide rich feeding places for fish communities, mainly those varieties which are commercially very important.
- The region is endowed with 127 fish landing stations of which 87 are located between Point Calimore and Pamban in the Palk Bay and 40 in the Gulf of Mannar.
- The fish community is comprised of 600 varieties of fishes of which 200 varieties are commercially very important.
- Since the Gulf of Mmanar and the Palk Bay are closed marine ecosystems, they are very sensitive and are quite different from open sea ecosystems.

Oppositions to the SSCP

The ecologists, academicians, politicians, non-govt. voluntary orgaizations (NGOs) and local fishermen communities raised strong voices of protests including petition in the court of laws against the execution of the Sethusamudram Ship Canal Project on several grounds as given below. It may be mentioned that the operation (dredging) of the project was formally inaugurated by the Prime Minister of India in the first week of July 2006.

The environmentalists and ecologists have objected the project on the following grounds :

- There would be catastrophic effects on fisheries, and the large fishing communities of the east coasts of Tamil Nadu would be adversely affected and they would lose their livelihood.
- The dredged canal would disturb the existing sea dynamics and will generate powerful currents between the Palk Bay and the Gulf of Mannar. The thermal condition of sea water in Mandapam region will be disturbed and consequently undersea marine forests will be destroyed.
- The Gulf of Mannar and the Palk Bay are separate closed marine ecosystems with their different ecological characteristics and sea dynamics. The construction of ship canal will amalgamate both the ecosystems which may damage marine life. The ship traffic may destroy marine ecosystem. It may be mentioned that hetherto these two marine ecosystems are like lagoons due to shallow depth of water housing rich biological communities.
- The marine ecosystems of coastal shallow water provide livelihood to lakhs of fishermen of 140 coastal villages of Ramnathpuram and Tuticorin districts.

- Since coral reefs are seat of biological diversity and provide ideal habitats to many species of sea plants and animals, but if corals are destroyed hundreds of species of marine animals will be killed due to starvation. This will upset the marine food chains and food webs.
- Marine sanctuaries, which are hetherto well protected, will be lost for ever.
- The sea grass meadows and weeds form rich marine ecosystems which support dugongs, which is an endangered species. Sea grasses and sea weeds also act as natural protective walls against marine erosion. The dredging of ship canal would damage the marine ecosystem. The dugongs would become extinct and marine erosion would be accelerated.
- The basic characteristics of the Gulf of Mannar Biosphere Reserve and 21 islands designated as 'marine national parks' will be lost for ever.
- The NEERI has already cautioned in its EIA report that if hard bedrocks of Adam's Bridge are encountered during dredging operation, blasting of rocks would be required. Ecologists say that if powerful blastings are effected, the resultant shock waves would drive [illegible] away and kill fish communities (due to sound effects).
- The NEERI's EIA report does not throw light on detailed aspects of damage/destruction to ecological set-up of the Gulf of Mannar Biosphere Reserve.
- No major studies of adverse effects on flora and fauna have been carried out in long-term perspective.
- Excavation/dredging of canal would generate 62 million tonnes of silts and sands, the dumping of which would disturb the sediment budget of the region.
- The fishermen alleged that their access to the sea would be regulated and restricted due to frequent plying of ships.
- Periodical dredging of the canal is necessary to enable free plying of mother and container ships. This would not be cost-effective, and periodical generation of sands and silts would not allow the marine organisms to adjust with the disturbed marine environment.
- Fishermen of Dhanushkodi are frightened of their displacement as they may be evacuated to other places. So they fear that they would be deprived of their livelihood as they totally depend on fishing.

The government officials maintain that all the issues raised by ecologists have been properly addressed and taken care of. The NEERI Environmental Impact Assessment has already suggested suitable places for the dumping of dredged materials. The government has taken due care of ecological problems and interests of local population and has assured that ecological issues, marine biological wealth, environmental quality and the welfare of fishermen communities of the project area would be maintained at all costs.

The fact is that the project has been launched. Let us hope for its completion in time. When the shipping cannal becomes operational in future, only then the environmental and socio-economic problems, if any, would surface.

23.5 CONTROL OF ENVIRONMENTAL DEGRADATION AND POLLUTION AND MAJOR ENVIRONMENTAL PROGRAMMES

Causes and processes of environmental degradation and pollution and their remedial measures have already been discussed in detail in the preceding chapters viz. man-induced soil erosion and sedimentation (chapter 16); environmental degradation (chapter 20); natural hazards and disaster management (chapter 17); terrestrial hazards and disaster (chapter 18); atmospheric hazards and disasters (chapter 19), and environmental pollution (chapter 21). Thus in order to avoid repetition the discussion on the control of environmental degradation and pollution, and hazards and disasters is not reproduced here again. Only a few major environmental programmes of global importance are being mentioned here.

It has been emphasized throughout this book that increasing impacts of human activities on natural environment have caused environmental degradation and pollution at local, regional and global levels. Thus the lowering of environmental quality has aroused international awareness about man-environment interactions and environmental crisis of global concern. Consequently, a number of progammes and projects have been formulated by international organizations to tackle the environmental problems caused by man himself and also by natural processes. The following are the important international organizations, porgrammes and projects which aim at the study of man-environment interactions, the environmental problems coming therefrom and possible solutions thereof.

1. International Biological Programmes (IBP)

The IBP is an international programme of research concerned primarily with the **'biological basis of productivity and human welfare'**. The programme was initiated by the International Council of Scientific Unions (ICSU) in 1964 but now the IBP works in collaboration with many other international organizations and programmes such as (i) United Nations Educational, Scientific and Cultural Organisztion (UNESCO); (ii) the World Health Organization (WHO); (iii) the World Meteorological Organization (WMO), (iv) the Food and Agricultural Organization (FAO); (v) International Unions of Biological Sciences (IUBS); (vi) International Unions of Biochemistry (IUB); (vii) International Unions of Physiological Sciences (IUPS); (viii) International Geographical Unions (IGU); (ix) Scientific Committee on Oceanic Research (SCOR); (x) International Unions for the Conservation of Nature and Natural Resources (IUCN); (xi) International Union of Nutritional Sciences (IUNS); (xii) International Unions of Anthropological and Ethnological Sciences (IUAES) etc. The IBP has the following seven sections for the study of various aspects of biological basis of productivity and human welfare :

(1) **Productivity of Terrestrial Communities (PT)** : involves the study of primary productivity through autotrophic green plants, secondary productivity through herbivorous and carnivorous consumers dependent upon primary producer green plants and decomposition of organic matter by decomposers.

(2) **Production Processes (PP)** : involves trapping and utilization of solar energy for photosynthesis by plants, transpiration by plants and nitrogen cycle.

(3) **Conservation of Terrestrial Communities (CT)** : involves the study to provide scientific conservation of natural habitats and species.

(4) **Productivity of Freshwater Communities (PF)** : involves the study of primary and secondary productivity by aquatic organisms in the rivers, lakes and ponds.

(5) **Productivity of Marine Communities (PM)** : involves the study of productivity of marine organisms in the inshore waters and the estuaries and the conservation of marine ecosystems and habitats.

(6) **Human Adaptability (HA)** : study of human ecology and adaptation of human beings to different environmental conditions.

(7) **Use and Management of Biological Reseources (UM)** : involves the management of ecological resources including both, plants and animals.

2. Special Committee for International Biological Programme (SCIBP)

SCIBP looks after the activities of International Biological Programme (IBP) and it is an ICSU organization with its headquarters at London.

3. Man and Biosphere Programme (MAB)

The MAB is an international interdisciplinary research programme which was initiated by the UNESCO in 1970 to study exclusively the theme of management problems arising out of interactions between human activities and the natural environment. In fact, this programme envisages an ecological approach to the study of interrelationships between man and natural environment. The main objective of MAB is to devise ways and means for rational and judicious use and conservation of ecological resources of the biosphere; to improve the global relationship between man and natural environment; to predict the future effects of present-day human activities on the environment and to manage ecological resources on scientific bases. The MAB adopts two-fold scientific approach to study (i) the ecosystems and comparison of natural, man-managed and urban ecosystems, and (ii) the impact of human activities of natural environment and in turn the impact of environment on man. The following are the scientific projects of MAB in collaboration with different relevant intergovernmental organizations and non-government organizations (NGOs) :

Project 1 : 'Ecological effects of different land use and management practices of temperate and Mediterranean forest landscapes.'

Project 2 : 'ecological effects of increasing human activities on tropical and subtropical forest ecosystems'.

Project 3 : 'impact of human activities and land use on grazing land : savanna grassland (from temperate to arid areas)'.

Project 4 : 'impact of human activities on the dynamics of arid and semi-arid zones ecosystems, with particular reference to effects of irrigation'.

Project 5 : 'ecological effects of human activities on the value and resources of lakes, marshes, rivers, estuaries and coastal zones'.

Project 6 : 'impact of human activities on mountain ecosystems'.

Project 7 : 'ecology and rational use of island ecosystem'.

Project 8 A : 'co-ordinated worldwide network of protected areas'.

Project 8 B : ' conservation of animals and plants, including micro-organisms'.

Project 9 : 'ecological assessment of pest management and fertilizer use on terrestrial and aquatic ecosystems'.

Project 10 : 'effects of man and his environment on major engineering works'.

Project 11 : 'ecological aspects of energy utilization in urban and industrial systems'.

Project 12 : 'interactions between environmental transformations, and genetic and demographic changes'.

Project 13 : 'perception of environmental quality'.

Project 14 : 'research on environmental pollution and its effects on biosphere'.

4. International Hydrological Decade (IHD)

1965-1974

5. International Hydrological Programme (IHP)

IHP is an UNESCO sponsored project to study the impact of human activities on hydrological and ecological processes. The International Association of Hydrological Sciences (IAHS) and other Non-Government Organizations (NGOs) also help in the International Hydrological Programme.

6. Integrated Project on Arid Lands (IPAL)

IPAL was launched by the UNESCO in 1976 under MAB with financial assistance from the United Nations Environment Programme (UNEP). The project aims to provide the scientific basis for the rehabilitation and rational development of arid and semi-arid zone ecosystems, through integrated programme of research, training and demonstration.

7. Scientific Committee on Problems of Environment (SCOPE)

It was created by the International Council of Scientific Unions (ICSU) in 1969. Its objectives are to coordinate the relevant activities of the constituent organizations of the ICSU and 'advancing knowledge of the influence of human activities upon the environment and the effects of the resulting change of human health and welfare, with particular attention to those influences which are global and common to several nations'.

8. United Nations Environment Programme (UNEP)

This programme of the UNO is specifically meant for implementing the recommendations of the conferences, seminars and symposia on environment organized by the UNO from time to time. Initially, it was created to implement the recommendations of the Stockholm Conference on Human Environment in 1972 and of the United Nations Conference on Desertification held in Narobi in 1977.

9. Scientific Committee on Oceanic Research (SCOR)

This committee emphasises research on oceanic pollution and aspects of river inputs to ocean system (RIOS).

10. International Center for Integrated Mountain Development (ICIMOD)

ICIMOD was created in 1981 under MAB programme with the following 6 goals :

(a) State-of-the art survey reports and workshops.

(b) Initiation of ICIMOD professional cooperation and information exchange on an international basis.

(c) Development of multi-disciplinary team approach to integrated mountain development,

(d) Establishment of an ICIMOD scientific publication series.

(e) Establishment of communication programme using news letters, audio-visual materials, and new media connections, and

(f) Formulation of longer-term organization and staffing requirements.

The following were the thrust areas of research of Phase I of ICIMOD to be completed by 1985 :

(a) Watershed resource management,

(b) Off-farm employment generation,

(c) Rural energy planning, and

(d) Engineering in fragile mountain environments.

11. Scientific Committee on Water Research (COWS)

12. International Decade for Natural Disaster Reduction (IDNDR, 1991-2000 A.D.)

IDNDR was an United Nations Sponsored 'programme for reducing loss of life, property damage, and social and economic disruption caused by natural disasters through concerted international activities'. The following were the major goals of IDNDR :

(a) to improve the capacity of each country against natural disasters by the establishment of early warning systems;

(b) to foster science and technology aimed at closing critical gaps in the knowledge to reduce natural disasters;

(c) to disseminate existing and new information related to assessment, prediction, prevention and mitigation of natural disasters, and

(d) to develop measures for the assessment, prediction, prevention and mitigation of natural disasters through various modalities and demonstration projects.

There are many more orgnisations, programmes and projects which are actively engaged in the study of man-environment relationships, the effects emanating from such interactions and their possible remedial measures at international levels. It is a healthy sign that international cooperation is available for the mitigation of severe environmental problems affecting the mankind at global level such as depletion of ozone layer and increasing greenhouse effect. For example, Montreal Protocol to reduce the production and consumption of CFCs (chlorofluorocarbons), international conference on ozone depletion organized by U.K. and United Nations Environment Programme (UNEP) involving 150 countries and a number of leading international scientists and industrialists on March 5 to 7, 1989 at London, and the conference on ozone destruction in June 1990 at London are sufficient enough to demonstrate active international cooperation in the study and mitigation of environmental problems. The first earth summit (Rio Conference) held in 1991, the second Earth Summit in 1996, the Kyoto Protocol (1997), the World Summit on Sustainable Development (known as Plus Ten Summit) or Third World Summit (Johannesberg, 2002) etc. and Intergovernmental Panel on Climate Change (IPCC), the UNO-sponsored programme to monitor climate change etc. are recent programmes to tackle man-induced environmental problems.

23.6 WORLD SUMMIT ON SUSTAINABLE DEVELOPMENT (PLUS TEN SUMMIT)

The word 'sustainable' is prefixed to many aspects of nature and society e.g. 'sustainable nature', 'sustainable environment', 'sustainable resources', 'sustainable use', 'sustainable economy', 'sustainable development', 'sustainable society' etc. The word 'sustainable' is generally used to indicate all those activities which can continue for longer period of time but no long-term guarantee of sustainability may be ensured 'because many factors remain unknown or unpredictable (Caring for the Earth). According to WCED (World Commission on Environment and Development) sustainable development has been defined as 'development that meets the needs of the present without compromising the ability of future generations to meet their own needs' while according to ICUN, UNEP and WWF 'sustainable development means improving the quality of human life while living within the carrying capacity of supporting ecosystems'. The terms 'sustainable growth' and 'sustainable use' are misleading because no physical thing can grow indefinitely and sustainable use may be applicable in the case of renewable resources only. The use of, for example, mineral resources can never be sustainable. Sustainable development, thus, can be defined as 'an overall socio-economic growth of the society through rational exploitation and optimum utilization of resources by adopting ecofriendly technologies, environmental education and knowledge, better organization leading to sustainable economy and maintenance of environmental quality and ecological balance so that continuous yield of resources is ensured to the present and future generations' (Savindra Singh, 2003). Thus, the ultimate goal of sustainable development should be two fold i.e. (1) to provide a strategy for such a development that can really improve the quality of human life, and (2) to provide a strategy that ensures conservation of the 'vitality and diversity of the earth'. Sustainable development must be both 'people-centered' **(anthropocentric)** and 'nature/environment centered' **(ecocentric)** as the development is a compromise between human material progress and maintenance of environmental quality'. Thus, conservation (of environmental quality and ecological resources) and development (of society) should be taken as integral components of one process.

If the development becomes sustainable, the society also becomes sustainable. The Caring for the Earth (1991) has set out the following principles (guidelines) for sustainable society :

1. coexistence and harmonious community life by respecting each other,
2. improvement of quality of human life,
3. conservation of (i) life supporting systems, and (ii) biodiversity,
4. ensure that uses of renewable resources are sustainable,
5. minimise the depletion of non-renewable resources,
6. maintian earth's carrying capacity,
7. change personal attitude and practices towards resources and environment, .
8. self care for the environment,
9. link development with conservation, and
10. create global alliances.

It may be mentioned that **'an environmentally sustainable global economy'** became the central goal of the U.N. Conference on Environment and Development (UNCED) popularly known as **First Earth Summit** or **Rio Summit** held in Rio de Janeiro in 1992. The broad goals of the First Earth Summit contained in Agenda 21 aimed at achieving 'sustainable development.' Consequently, 'United Nations Commission on Sustainable Development' (CSD) was set up to 'review national implementation of Agenda 21 and to provide high-level coordination among various U.N. environment and development programmes' (State of the World, 1997).

In order to focus the central theme of the first two earth summits (1992 and 1997) the **World Summit on Sustainable Development** also known as **Plus Ten Summit** or **Third Earth Summit** was held from August 26 to September 4, 2002 in Johannesburg, the capital of the Union of South Africa. The summit was represented by about 9000 participants from different countries. About 225 hours were spent in discussing and preparing strategies for different issues but nothing substantial could be achieved in the implementation of various agreements which were agreed upon during the first earth summit held in 1992. The main goal of this summit was to strike an agreement on 150 clauses of the **Plan of Implementation** related to improve the health of the earth and its inhabitants.

It may be mentioned that the responsibility of the world community for caring and protecting the earth and its vitality was determined through Agenda 21 in the 1992 Rio Summit. As per agreement the developed countries were desired to spend 680 billion American dollars on various environmental programmes and each developed country was to contribute 0.7 per cent of its gross national product (GNP) in the form of **Official**

Development Assistance (ODA) to the developing countries but nothing substantial could be achieved. The share has declined to only 0.29 per cent of GNP. The expenditure on the summit came to about Rs. 275 crores (2750 million rupees) but no concrete result could be achieved. The only success of the summit was that the agreements signed in Rio (1992), Montrey and Doha (2001) could not be opened up again for rediscussion. It may be concluded that if we could not march ahead, at least we could not retreat. The following issues were discussed and some ambiguous agreements—disagreements were arrived at :

1. Poverty Eradication

It was decided by the governments before the Johannesburg Summit that the number of poor people having daily income of one dollar would be reduced to half by 2015. It was agreed that a **World Solidarity Fund** (WSF) would be set up for the eradication of poverty but no guidelines could be prepared for contributions to this fund and its management and operation. Contribution was made voluntary and the matter related to the formulation of modalities of the operation of this fund was left to the General Assembly of the UNO.

2. Trade

It may be mentioned that the subsidy, which is responsible for imbalancing the world trade, is a barrier in the sustainable development. The developing countries expected that the developed countries would agree to withdraw subsidies, which are responsible for imbalancing trade, in phases, to provide better market facilities for poor countries, and to stop giving heavy subsidies on agriculture (amounting to one billion US dollars per day) in their own countries but nothing could happen. European Union (mainly France) and United States strongly opposed and rejected the proposals of developing countries to reduce subsidies on agriculture in their own countries to open their markets for the products of developing countries.

3. Biodiversity

It was commonly agreed to reduce substantially the number of rare and threatened species of plants and animals facing extinction by 2010 A.D. It was also agreed in principle that the developing countries would be paid the share of profit coming out of the use of their gene property of biodiversity of plants and animals.

4. Water and Sanitation

Inspite of stiff opposition by United States, Japan, Australia and New Zealand it was agreed to reduce the number of people deprived of safe drinking water by 50 per cent by 2015 A.D. but no target could be decided for improvement in sanitation.

5. Fisheries

It is necessary to maintain a required stock of marine fishes in order to maintain marine ecological balance. The present rate (upto 2002) of catch of marine fishes is so alarming that these may face extinction in near future. It was agreed to compensate the loss of the stock of marine fishes upto 2015 A.D.

6. Renewable/Non-Conventional Energy

It was proposed to increase the share of non-conventional energy by 15 per cent upto 2010 in the overall consumption of total energy but no agreement could be reached because no target could be fixed under the pressure of the United States and oil producing countries. It was only agreed that the production and consumption of non-conventional energy should be increased.

7. Good Governance

It may be mentioned that the sustainable development requires sufficient capital and advanced technologies, which are lacking in the developing countries. On one side the developing countries were crying for good global governance, on the other side the developed countries were pleading for good national governance. No agreement could be reached on transfer of technologies.

8. Sustainable Production and Consumption

The developing countries, mainly India, raised the issue that over-production and over consumption were not sustainable. If the present level (2002) of consumption in the United States was carried to other countries, many more earths like the present one would be required to meet the demand of necessary resources. The developing countries pleaded for changes in the life style in the developed countries but they did not agree. It was only agreed that a 10-year plan should be prepared to make the production and consumption sustainable.

Monitoring of WSSD

The Commission on Sustainable Development (CSD) is the apex intergovernmental body of the UN for sustainable development. The 11th Commission on Sustainable Development (CSD-11) met in its UN headquarters in the United States of America from April 28 to May 9, 2003 to review and monitor the progress of actions taken since World Summit on Sustainable Development (WSSD) held in Johannesburg in September, 2002 and also to review the progress of pledges made in earlier two summits (Rio Summit in 1992 and Kyoto Summit in 1997). The CSD-11 prepared the scheme of Implementation Cycles comprising two-yearly action-oriented sessions of total 7 cycles starting from 2004 to 2017. The implementation cycles have the following specific objectives :

1. to review earlier pledges and commitments made in different summits ;
2. to make further policy suggestions for future summits ;
3. the first year of each cycle would be devoted for Review Session while the second year would be of Policy Session ;
4. each cycle will have specific issues e.g. the first cycle will focus attention on water, sanitation, and human settlements ; and
5. some of the 'crosscutting issues like poverty eradication, changing unsustainable patterns of consumption and production, protecting and managing the natural resources base of economic development and means of implementation (Down to Earth, June 15, 2003, p. 16) will also be reviewed and monitored throughout seven-cycle period.

24

BIODIVERSITY, BIOSPHERE RESERVE AND WILDLIFE CONSERVATION

The biosphere, termed as biological factory of living organisms, is characterized by different life forms of living organisms including both plants and animals communities of varying ecosystems. The natural ecosystems having almost similar biotic and abiotic conditions are called biomes wherein we study different aspects of biological communities together with physical conditions of the habitats. Since the natural ecosystems vary horizontally i.e. from equator towards the poles and vertically i.e. from sea level upward and from sea level downward and hence different biomes have developed having distinct physical and biological characteristics. Thus the number of varieties of species of plants and animals is very significant indicator of the health and wealth of a nation. This biological variety forms the basis of biological diversity or simply biodiversity. The study of biodiversity includes the consideration of meaning and concepts, types, benefits, causes of loss and conservation of biodiversity. The biosphere reserves represent well protected wild areas meant for the conservation of wild life comprised of plants and animal communities together with physical habitats. In fact, biosphere reserves and wildlife conservation are effective means of not only conserving but also increasing biodiversity in protected areas.

24.1 BIODIVERSITY

The comprehensive study of biodiversity is very important for the conservation and increase of biodiversity of a nation because the status of biodiversity determines the health and wealth of the nations. The study of biodiversity includes the following aspects :

- meaning and concepts of biodiversity,
- types of biodiversity,
- benefits of biodiversity,
- causes of the loss of biodiversity, and
- conservation of biodiversity.

Biodiversity : Meaning and Definitions

Biodiversity simply means variety of living species of organisms of both plant and animal communities in an ecosystem having certain specific environmental conditions and larger spatial scale, such as tropical rainforest ecosystem, savanna ecosystem, temperate grassland ecosystem etc. Here, ecosystem is taken at biome level. The term **biodiversity** was first coined and used by Walter G. Rosen in the year 1986.

In fact, the term biodiversity is the contraction of the term **biological diversity** which was used by Thomas E. Lovejoy of the USA (a biologist) in the year 1980. The concept was popularized worldover by E.O. Wilson. It may be mentioned that biodiversity has been variously viewed and defined in many ways but the elements of variety of genes, species and ecosystems (physical environmental conditions) have been at the core of almost all of the definitions of biodiversity as mentioned below :

'Biodiversity is the **diversity** of different **species** together with **genetic variation** within each species in a given **area** (ecosystem)'.

C.J. Barrow (2005)......(1)

'Biodiversity is the totality of **genes, species,** and **ecosystems** in a **region'.**

United Nations Environment Programme (UNEP)......(2)

'Biodiversity is the ensemble and interaction of **genes, species,** and ecological diversity of a given **place** and **time'.** de Castri (1996)......(3)

Biodiversity can be difined as 'the diversity of life, which includes the full range of variety and variability within and among living organisms and the ecological complexes in which they occur and encompasses ecosystem or community diversity, species diversity and genetic diversity.'

Y. Anjaneyulu (2004)......(4)

It is apparent from the aforesaid definitions of biodiversity that there are four elements of biodiversity namely, genes, species, ecosystem (area) and time. Thus, biodiversity is viewed in terms of variety and variability of living organisms with reference to genetic, species, ecosystem and temporal variations Thus, biodiversity may be finally defined as follows :

'Biodiversity refers to the variety and variability of living organisms of a given area or a region or an ecosystem in terms of diversity of genes, species and ecosystems, at a given time span, and is characterised by spatial and temporal changes'.

Savindra Singh (2007)......(5)

Elements and Types of Biodiversity

Based on above discussion the following **elements of biodiversity** are identified :

- **Genetic variation,** which determines richness of biological variety of a given ecosystem because genetic variation within and between the populations of species of a region, say ecosystem determines the nature and process of reproduction of species, productivity, adaptability to certain or complex environmental conditions and changes therein, viability, mutualism etc.
- **Species variation,** means variety of species of biological communities comprising species of plants, animals and micro-organisms of a given ecosystem. Species variety and variation determine the richness or poorness of biodiversity and ecosystem stability and ecological balance. The greater the variety and number of species, the larger and more complex is the food chains and hence richer is the biodiversity and more stability of ecosystem, and vice versa.
- **Ecosystem variation,** is characterized by different types of ecosystems having certain suites of physical environmental conditions together with biological communities. In fact, ecosystem diversity refers to habitat diversity and different ecological processes operating therein.
- **Temporal variation,** refers to different time spans in terms of successional development of biotic communities. The biodiversity of a region is always considered in terms of timal factor i.e. the status of biological communities in the past, at the present time, and in future. Here we also study the processes of evolution and extinction of species and their future status.

Based on the elements of biodiversity it is basically divided into the following 3 types :

1. genetic diversity,
2. species diversity, and
3. ecosystem or habitat diversity.

(1) Genetic Biodiversity : Genetic diversity is considered as variations and differences at the levels of genes in the species of plants and animals. In fact, gene diversity determines differences in species and the degree of species differences determines the levels of biodiversity i.e. richness or poorness. 'More genetic diversity within a species means greater variability and adaptability of individuals (of a species) to environmental conditions. Lesser genetic diversity on the other hand, leads to uniformity (of species) and thus greater susceptibility to environmental changes' (D.R. Batish, 2006).

(2) Species Biodiversity : Species biodiversity simply means variety and variability of species of biological communities (plants, animals and microbes) of a given ecosystem. It may be mentioned that species diversity is generally taken as the synonym of biodiversity because species diversity refers to the variety and number of different types of individual populations of living organisms in an ecosystem. For example, number of species of plants and animals including micro-organisms, variety and number of individual populations of organisms of each species in equatorial rainforest ecosystem, monsoon deciduous forest ecosystem, savanna ecosystem etc. It may be mentioned that it is the size of species diversity that makes the food chains longer or shorter which in turn determine the degree of biodiversity. The greater species diversity makes longer food chains which in turn make rich biodiversity as is the case of the equatorial rainforest which has become **'biodiversity hotspot'** (richest biodiversity in the world).

(3) Ecosystem Biodiversity : Since ecosystems determine the variety of habitats and niches for biological communities, biological processes operating in each natural ecosystem, all of which in turn determine the variety and number of species in different ecosystems, and hence biodiversity is also considered at ecosystem level e.g. equatorial rainforests, coral reefs, estuaries, grasslands etc. In fact, the physical environmental conditions (land and soil, air-weather and climate, water etc.) determine the nature and variation of hubitats for different biological communities.

Biodiversity Hotspots

The term **'biodiversity hotspots'** was first coined and used by Norman Myers, a British ecologist, in the year 1998. He defined biodiversity hotspots as those areas which have rich biological communities including plants, animals and microorganisms wherein endemic species predominate. He identified 10 such very rich biodiversity areas i.e. biodiversity hotspots in the tropical rainforest biomes. Now, 34 biodiveristy hotspot areas have been identified in the world. It may be mentioned that endemic species are those species of plants and animals including micro-organisms which are found in a specific area only and are not found in other areas. Only those rich biodiversity areas are disignated biodiversity hotspots which have atleast 1,500 species of endemic vascular plants and have lost 70 percent of their original habitats.

The regions or areas/localities having richest biodiversity are called **'biodiversity hotspots'** or **'megadiversity regions or localities'**. The hot-spots of biodiversity are, in fact, such areas which are characterized by high level of biological diversity and large percentage of endemic species such as Amazonia, Malaysian peninsula, New Zeland, Madagascar, South Africa, North-eastern Australia, Borneo, west Afirca, Western Ghats of India, Philippines, tropical Andes including Venezuela, Columbia, Ecuador, Peru, and Bolivia, eastern Indonesia (Wallacea), Antilles, Cerrado of Brazil, south-western Australia, eastern Himalayas, Tasmania, eastern Mediterranean region, Polynesia and Micronesian islands, Hawaii etc. In all, about 34 hot-spots of rich biodiversity have been identified in the world of which 3 hot-spots are found in India e.g. (1) Western Ghats, (2) North-Eastern India, and (3) Himalayas.

(1) **Himalayan Biodiversity Hotspot Region** comprises rich biological communities of Uttarakhand, Sikkim, Arunachal Pradesh and sub-Himalayan West Bengal of India, Nepal, Bhutan and Yunnan province in S.W. China. The region is characterized by more than 10,000 plant species. About 32 per cent of the total plant species are endemic. In Sikkim alone (geographical area = 7298 km^2) there are more than 4200 plant species of which about 60 per cent are endemic. Indian regions of the Himalayan ecosystem are endowed with more than 5800 species of plants out of which about 36 percent are endemic species. Nepal is characterized by more than 7000 floristic species of which 8 per cent are endemic while Bhutan has about 5000 plant species which are comprised of about 15 percent endemic species. It may be mentioned that a sizeable percentage of species is commonly found in many Himalayan countries because these are overlapping in India, Nepal and Bhutan. This is why average number of plant species of this hotspot region is about 10,000 species.

(2) **Indo-Burma Biodiversity Hotspot Region** comprises rich biological communities of North-Eastern states of India and adjoining Myanmar (Burma). Indian region includes the states of Nagaland, Meghalaya, Manipur, Assam and Tripura. Besides rich floristic species the region is also characterized by numerous species of freshwater animals, birds, and other endemic animal species.

(3) **Western Ghats Biodiversity Hotspot Region** is characterized by very large number of endemic plant species i.e. about 52 per cent of total plant species of this region are endemic to this region. The Western Ghats ecosystem is spread over the western margins of the states of Maharashtra, Karnataka, Tamil Nadu and Kerala. The Agasthymalai Hills and the Silent Valley (New Annambalam Reserve Basin) are very important rich biodiversity areas within this area. The region is

characterized by several endemic species of plants of evergreen and deciduous forests but the region is under tremendous threats of rapid rate of loss of biodiversity and habitats due to deforestation and execution of many development projects. Consequently, several rare species of plants and animals (such as Asian elephants) are now endangered species.

Value and Importance of Biodiversity

The value and importance of biodiversity are viewed in terms of benefits we get directly or indirectly from biological communities comprising plants, animals and micro-organisms. The newly emerged discipline of **'ecological economics'** deals with economical, ecological, environmental, and social (human) services (benefits) of ecological resources. Besides, ecological resources, and therefore, biodiversity, are also important politically and religiously. The following approaches are in practice to assign value of biodiversity on two bases :

Bases of biodiversity value
- economic value basis
- ecological value basis

Or

- direct value or direct use value
- indirect value or non-use value

Direct use value : refers to the assignment of value to those ecological products which are directly harvested from plants and animals (biological communities) such as food, seeds, timber, skins, furs etc. Such benefits accruing directly from biological communities are also called as **tangible benefits** which are in fact economic benefits.

Indirect use value : is assigned to those ecological resources which are **intangible** and are not directly exploited and consumed, such as sight seeing, bird watching, animal watching etc. These are collectively called as **eco-tourism** wherein we include the places of prestine (original) environment i.e. places having undisturbed wild areas, known as **'natural bioparadise'**. The other items of indirect use of biodiversity include ecosystem/ecological services such as purification of air and water, moderation of weather and climate, absorption of emission of carbon dioxide from anthropogenic sources, regulation of hydrological cycles, functioning of biogeochemical cycles, creation and maintenance of soils and enrichment of soil fertility etc.

On an average, the benefits of biodiversity may be grouped in the following categories :

- **Ecological services (benefits) or ecosystem services**

  Examples :

  (1) conservation and protection of water,
  (2) purification of air,
  (3) creation, protection and conservation of soils,
  (4) moderation and regulation of weather and climate,
  (5) regulation and function of hydrological cycle,
  (6) function and regulation of bigeochemical cycles,
  (7) maintenance of ecosystem stability,
  (8) absorption of carbon dioxide emitted from anthropogenic sources,
  (9) aesthetic value,
  (10) ethical value, natural wild areas as **'nature museum'** for future generation, etc.

• Economic Services (Benefits)

The economic benefits from rich biodiversity are in the forms of consumptive use of products and productive use as follows :

- ➤ source of food,
- ➤ clothing,
- ➤ shelter (for aborigins),
- ➤ vitamins,
- ➤ drugs and medicines,
- ➤ fuel wood and commercial timber,
- ➤ sports goods,
- ➤ tourism,
- ➤ industrial raw materials,
- ➤ genetic storehouse etc.

Besides, biodiversity has also political and religious significance as political stability/instability, diplomatic relations, religious faith etc. are closely related with biological resources and biodiversity. There have been several cases of infringement of property rights and patent rights between agencies of developed nations and developing nations having rich biodiversity. The advancement in biotechnology has made biodiversity more relevant and important.

The importance of biodiversity and its conservation was given more importance during the first Earth Summit (Rio Conference) held in the year 1992 in Rio de Janeiro. This aspect will be discussed in the last topic of this section.

Biodiversity Loss

Extinction of species is a process of loss of biodiversity. Species extinction (of plants, animals and microbes) is defined as complete elimination of a specific species of biological community from natural habitats as well as from cultivation or captivity as 'zoos' and protected areas. Before the appearance of 'economic man' on this planet earth species extinction was caused only by natural processes but now anthropogenic processes of species extinction has outplayed natural process. For example, the rate of extinction of species has increased phenomenally after 1850 due to increased human economic activities, the average rate of extinction was two to three species per decade between 1600 and 1850 but thereafter the rate increased to 1,000 species per decade. As per estimate of Paul Ehrlich, one third to two-thirds of all species currently existing on this planet earth may become extinct by 2050 A.D. According to other estimate by the scientists the known species of the earth are 40,000,000 out of which 10,000 species are becoming extinct every year due to human economic activities such as extension in agricultural land, increase in agricultural productivity, construction of dams and reservoirs, deforestation and accelerated soil erosion, industrial development, urbanization, environmental pollution etc. Table 24.1 denotes extinction of species by natural processes in historical (geological) periods.

Table 24.1 : Mass extinction of biological communities.

Historic Period	Time (before present)	Extinction
Ordovician	444 million	25 percent of all families exticnt
Devonian	370 million	19 percent of all families extinct
Permian	250 million	54 percent of families, 90 percent of species extinct
Triassic	210 million	23 percent of families, 1/2 species extinct
Cretaceous	65 million	17 percent of families, 50 percent species extinct (including dinosaurs but not mammals)
Quaternary	Present	1/3 to 2/3 of all species extinct if present trends continue ?

Source : William Cunnigham and Mary Ann Cunnigham, Principles of Environmental Science, 2003.

Recent Trends of Biodiversity Loss

- world biodiversity loss by 27 percent between 1970-2005.
- population of terrestrial species declined by 27 percent between 1970-2005.
- population of marine species declined by 28 percent between 1970-2005.
- population of freshwater species declined by 29 percent between 1970-2005 caused by the following factors consequent upon industry powered economic growth :
  - habitat loss
  - over exploitation of species
  - pollution
  - spread of invasive species
  - climate change due to global warming.
- terrestrial and freshwater species suffered most in tropical regions due to habitat loss as they declied by 40 percent.
- marine species population in South Atlantic, Southern Ocean, South pacific and Indian Ocean declined by 50 percent between 1995-2005 due to overfising, invasive species, pollution and green house gas emission.

Causes of Biodiversity Loss

As stated above, extinction of species and emergence of new species is a natural process of evolution. The extinction caused by nature is balanced by the evolution of new species but anthropogenically caused species extinction leads to mass destruction of biodiversity because natural process of extinction of species and loss of biodiversity is exceedingly a slow process wherein there is enough time for the evolution of new species but the anthropogenic process of species extinction and biodiversity loss is a very rapid one taking very little time span. The causes of biodiversity loss are grouped in two major categories as follows :

1. **Natural Causes**
    (1) climatic changes
    (2) volcanic eruption
    (3) collision of the earth with celestial bodies (meteors)
    (4) continental drift and fragmentation
    (5) drought and famine
2. **Anthropogenic Causes**
    (1) habitat loss
    (2) fragmentation
    (3) over exploitation
    (4) intensive agriculture
    (5) introduction of exotic species
    (6) diseases
    (7) environmental pollution
    (8) genetic transformation
    (9) tourism industry

1. Natural Causes of Biodiversity Loss

As stated above biodiversity loss is a natural process of evolution of biological communities. With time some species become extinct and some new species are evolved. Among the natural factors of biodiversity loss important causes are climatic changes at global level, prolonged drought and famine conditions, collision of the earth with celestial bodies such as asteroids and metoroids, volcanic eruption mainly fissure lava flow, continental drift and fragmentation etc. Onset of ice age and continental glaciation results in covering of ground surface with thick ice sheets, which results in mass extinction of species of biological communities. Two great ice ages, such as Carboniferous and Pleistocene ice ages, have been responsible for loss of several species of plants and animals. The collision of the celestial bodies with the earth results in the generation of immense volume of dusts which form thick veils in the lower atmosphere. These dust veils obstruct the solar radiation waves in reaching the earth's surface and hence temperature is remarkably reduced to very low amount of insolation reaching the earth. Such situation causes cold climate and thus the organisms of warm climates cannot adapt to sudden change in climatic conditions and hence die. Such situation happened during Cretaceous period when a giant meteorite collided with the earth and the resultant dusts caused mass extinction of dinosaurs. Besides, 50 percent of other species also disappeared. The Permo-Carboniferous glaciation of the Gondwanaland about 250 million years ago resulted in the loss of 54 percent of families, and 90 percent of species became extinct due to extreme cold condition. The rapid lava flow during fissure eruption of volcanoes covers larger areas and the existing species of plants and animals are buried under thick covers of hot lava and thus become extinct. Such situation occurred during Cretaceous period when there was widespread volcanic activity world over.

2. Anthropogenic Causes of Biodiversity Loss

A number of anthropogenic factors of biodiversity loss have been listed above. Habitat loss due to variety of factors, overexploitation of biotic resources for different purposes, introduction of exotic species, diseases, and environmental pollution are more important factors of biodiversity loss.

(1) **Habitat Destruction :** The fragmentation of habitats of species of plants, animals and microbes due to deforestation, construction of roads and railway tracks across natural ecosystems having rich biodiversity, mining activities, location of industries, construction of dams and reservoirs across major rivers passing through hilly and densely forested terrain etc. is the major cause of habitat destruction and loss which leads to large scale loss of biodiversity. Deforestation at everincreasing rate in many parts of the world has destroyed original places of endemic species. Large-scale deforestation in the Himalayan ecosystems, Western and Eastern Ghats of India has resulted in widespread loss of habitats of several species. Large areas of forest covers, woodlands and grasslands have been converted into agricultural farms, commercial forests and grazing pastures, throughout the world. Most of the temperate grasslands (e.g. Steppes of Russia, Prairies of USA and Canada, Pampas of Argentina, Veld of South Africa, Downs of New Zealand) have been now converted into croplands. Tropical rainforests, having richest biodiversity in the world, are being destroyed in many countries. Wetlands have been reclaimed for various purposes such as for urban settlements, cropland etc. The mangroves provide suitable habitats for a number of species of land and marine organisms but now larger chunks of mangroves have been destroyed under coastal region development programmes, shrimp farming and pisciculture.

It may be mentioned that **fragmentation of habitats** i.e. segmentation of habitats of large areal extent into smaller patches of habitats, reduces biodiversity as it separates populations of species into different isolated groups. reduces large habitats into small habitats, etc. Such situation impedes reproduction and speciation with the result isolated species become more vulnerable to diseases and extreme events such as volcanic eruption, prolonged droughts, atmospehric storms, tsunamis etc. and are ultimately lost.

(2) **Overexploitation :** The harvesting of wild animals and plants beyond a critical sustainable limit may be termed as overexploitation. Here, the scope of overharvesting has been limited to the species of land and animal species. The overexploitation of species includes both legal and illegal actions. Illegal hunting by poachers for such items of animals which have very high price in the world market has been responsible for either extinction or reduction in the number of rare species of animals in many parts of the world. For example, illegal hunting of rhinos (for their horns and hides), tigers (for their skins), elephants (for their tusks) has resulted in remarkable reduction in their numbers in India and these animals have been declared endangered species and are now protected in segregated areas. Rapacious hunting of great whales has made them rare species. The American passenger pigeons, once having a population of 3 to 5 billions, have now been completely eliminated due to uncontrolled overhunting and loss of natural habitats. Similarly, American bisons, whose population was about 60 million in 1850 but dropped to only 400 by 1890, have now become almost extinct. The advancement in fishing techniques (fuel propelled ships and large trawlers) has caused overexploitation of fishes of marine ecosystems. This has resulted into either exhaustion or remarkable decline in fish harvest. Illegal hunting of animals for commercial products such as fur, hides, tusks, horns etc. has also led to overexploitation of animals species resulting into enormous biodiversity loss. Smuggling business has been responsible for large-scale illegal hunting of animals.

(3) **Introduction of Exotic Species :** Intentional or unintentional introduction of exotic species of plants and animals in entirely different ecosystems having dissimilar habitats is a potent factor of biodiversity loss. The alien plants brought to different habitats have done great damage to native plants beyond sustainable limit with the result many species of plant communities either have become extinct or have been suppressed. Islands or isolated ecosystems are more vulnerable to exotic species. Lantana commara was brought to India for the purpose of forming hedges but now it has become a menace to native plants mainly in the forests. The inadvertent introduction of Congress grass (Parthenium hysterophorus), popularly known as 'gazar grass' (carrot grass) has resulted in the elimination of other native plants. In fact, it has now become a teething problem because it not only spreads at fast rate and covers croplands but also causes many diseases.

Some of the exotic plants brought to new habitats grow and spread very fast because of rapid rate of colonization, quick adaptation to new environment, efficient utilization of soil moisture and soil nutrients, weak resistance of native species etc. North America alone accounts for more than 4,500 exotic species of plants and animals. In the beginning European rabbits were brought to Australia to graze the widespread native grasses and to control their covers but the population of rabbits soon multiplied to such an extent that native grasses became endangered. In order to control rabbit population, European foxes were introduced in Australia which created another ecological problem. The deliberate transport of birds, rabbits and deers from Europe to New Zealand and the transport of several birds from Europe to North America caused significant biodiversity loss. Accidental (unintentional) transport of animals involves the carriage of animals attached with human bodies, his luggages, means of transport, commercial goods etc. For example, brown rats are now widely distributed throughout the world because of their undesired transport to various parts of the world through ships. The deliberate transport of animals by man from their native places to other different destinations has in some cases changed the natural distributional pattern of concerned animals.

The favourable environmental conditions of the regions where animals are transported by man whether by deliberate action or by accident, incourage rapid growth of populations of the transported animals and thus the spreading of concerned animals is accelerated. For example, one pair of European rabbits transported to Australia is capable of producing 90,00,000 offsprings within a period of only three years. European starling was brought to North America in 1989 and since then starlings have spread over larger area of the U.S.A. and Canada.

(4) **Environmental Pollution :** Pollution of land and soils, air and water causes immense loss to biodiversity of various natural ecosystems. Acceler-

ated rate of soil erosion consequent upon deforestation and faulty cultivation practices degrades the quality of land in terms of its productivity which in turn results in short supply of food for grazing animals and thus some of the animals either die of starvaton or migrate to other places. Increasing urbanization and industrialization, mechanization of agriculture, rapid rate of human population growth, 'use and throw away culture' of the western industrialized world etc. have caused heavy pollution of water (including both freshwater and seawater) and air. The high level of water and air pollution has resulted in phenomenal decrease of number of those species which are unable to tolerate pollution level and cannot adapt to the polluted environment. Not only the number of species of plants and animals has decreased due to heavy load of pollution but the variety of biodiversity has also decreased significantly. Some of the rivers have been so greatly polluted that they have lost their biological treasure. For example, the Damodar river has now become **'biological desert'** because of almost total loss of riverine organisms due to heavy pollution by industrial wastes of numerous industries, and slurry of coal washeries located along the banks of the river. Several such examples may be given to demonstrate the adverse impacts of pollution on biodiversity loss.

High doses of chemical fertilizers, herbicides, pesticides and insecticides to boost agricultural production and horticulture have so greatly polluted the soils that these toxic chemicals have reached the food chains and thus have caused mass deaths of several species of birds and animals. For example, vultures in India have become endangered species. It may be mentioned that the toxic chemicals have entered the bodies of grazing animals and the vultures feeding on the dead bodies of such animals are chemically poisoned and die, lead and mercury poisoning of animals causes their mass deaths. The air polluted by sulphur dioxide emitted from mills results in acid rains which in turn causes great damage to vegetation and animal communities. Widespread acid rains in Scandinavian countries (Normay, Sweden) have so heavily polluted the lakes that most of the lakes have lost their biological communities and are now biologically termed as **'dead lakes'**. Acid rains are very often called **'lake killers'** in Anglo-American and European countries. Forests of Canada, USA, Germany and many countries of middle Europe have been largely damaged due to acid rains resulting into great loss of biodiversity. Many more examples may be cited to demonstrate direct adverse impacts of pollution on biodiversity, i.e. the greater the pollution level, the higher the biodiversity loss and vice versa.

(5) **Global warming** and consequent **climate change** are the recent potent factors of depletion of biodiversity in different biomes. The impacts of rising temperature on vegetation communities mainly forests are now perceptible in taiga forests which have shown shrinking in their areas whereas increased rainfall due to temperature rise in the tropical regions has positive impact on forest growth. The rise in sea level due to melting of ice sheets consequent upon global warming may effect submergence of small islands with the result the biological communities of such isolated island ecosystem would be lost forever. Rise in sea temperature causes coral bleaching which results not only in the loss of corals but numerous other species of marine organisms which are provided suitable habitats in coral reefs. The coral bleaching during 1997-98, due to rise in average sea temperature by 2^0C, has been recorded as the most catastrophic event as it accounted for large-scale death of corals in the tropical oceans of 60 countries and island nations where it accounted for 70 percent death of corals off the coasts of Kenya, Maldives, Andamans and Lakshwadweep islands in the Indian Ocean and 75 percent coral death in the Seychelles Marine Park System and the Mafia Marine Park off Tanzania.

Other causes of biodiversity loss are diseases, genetic assimilation of certain organisms, trade in wild species for pets (such as birds, cats, dogs, fishes for aquarium), overharvesting of certain species etc.

Conservation of Biodiversity

The destruction of natural habitats of wildlife and biodiversity loss have assumed alarming proportion. The protection of natural habitats and wildlife has now drawn the attention of world communities so that there may be proper conservation of biodiversity. Though sporadic attempts were made since 1950 for the conservation and preservation of biodiversity at local to regional (national) levels but the first serious attempt to protect wildlife and biodiversity at international level was made in the year 1992 at first Earth Summit, known as Rio Summit, held at Rio de Janerio city of Brazil from December 3 to 14, 1992 under the aegies of United Nations for the protection of the earth and its environment, maintenance of ecological balance and to enrich biodiversity. The conference was attended by the representatives of 178 countries. Natural forests maintain rich biodiversity. Considering this fact the Rio Summit discussed the issue of forest conservation and resolved to protect natural and pristine forest but no tangible agreement could be arrived at due to strong protests from a few developed countries led by the USA.

The participants expressed grave concern at the Summit on fast rate of biodiversity loss. According to scientists the known species of the planet earth are 40,000,000 out of which 10,000 species are becoming extinct every year due to human economic activities (as elaborated earlier). Similarly, species of marine organisms are being destroyed due to pollution of seawater and coast development programmes. Thus, in order to check the loss of biodiversity a proposal for bioconservation was presented at the Rio Summit wherein it was provided that if the developed countries use the biological wealth of the developing countries then they would have to transfer their biotechnologies free of cost to the concerned developing countries and they should also share the profit from biological resources with the concerned country.

The U.S.A. refused to sign the proposed agreement on biodiversity on the pertext that the transfer of biotechnology comes under intellectual property and patent law and thus the proposal for the enrichment of biodiversity remained only a paper work.

Only 150 countries out of 178 participating countries could sign the agreement to enrich the biodiversity. The agreement of biodiversity included the following 3 programmes.

- to ensure conservation of biodiversity,
- sustainable use of biodiversity, and
- rational and equitable share of profit to acrue from the use of genetic resources.

According to this agreement the country should have complete control over its biotic resources and full right over the profit accrueing from them. If the biotic resources of a country are commercially used by another country, the country possessing the biotic resource can sign an agreement with the user country for sharing the profit occurring therefrom. This agreement was implemented in 1993 but no perceptible positive result of the desired goal could be achieved.

Before attempting ways of biodiversity conservation (**in situ** and **ex-suit conservation**) in specially protected areas such as nature reserve or biosphere reserve, national parks, sanctuaries etc. it is necessary to discuss the categories of species inorder of their status of survival or their risk factor for survival. A comprehensive list of different categories of species facing risks of their survival was prepared by the International Union for Conservation of Nature and Natural Resources (IUCN), which is now known as the World Conservation Union (WCU), in the year 1988. The list containing species of plants and animals which are threatened for their survival and are facing extinction is revised from time to time by the IUCN so as to update the list. Such lists are called **Red Data Books** or **Red Data Lists.** The 2004 edition of Red List of Threatened species released by the IUCN includes the following categories :

- **Extinct species (EX),** are those species of plants and animals which have been completely eliminated from both in natural wild areas and managed areas such as crop cultivation or hatcheries.
- **Extinct in Wild (EW),** are those species which have been eliminated and thus have become extinct in natural conditions in wild areas (natural areas) but some individuals of the species still survive in managed (by man) areas i.e. in cultivation or captivity.
- **Critically Endangered (CR)** species are those species which have lost their 80 percent population over the last 10 years time or 3 generations, whichever is longer.
- **Endangered (EN) species** are those species which have lost their 70 percent of population within the last 10 years or 3 generations of that species have undergone 70 percent reduction in their population, whichever is longer.
- **Vulnerable (VU) species :** A species becomes vulnerable to extinction when there has been a loss of 50 percent of its population over a period of last 10 years or for 3 generations whichever is longer.
- **Near Threatened (NT) species,** a species is termed as near threatened which is above the stage of the categories of critically endangered and vulnerable species but the loss of its population is high.

- **Least Concern (LC),** a species is put under the category of 'least concern' when its populations are abundant in wild areas.

Basically, there are two ways (methods) of conservation of biodiversity as follows :

(1) In-situ conservation , and

(2) Ex-situ conservation.

(1) **In-Situ Conservation :** The conservation of species of plants and animals in their natural habitats i.e. wild areas is called **'in-situ'** or **'on-site conservation'.** In this method of conservation of biodiversity species of plants and animals are protected in specially demarcated natural habitats such as 'nature reserve' or 'biosphere reserve', national parks, sanctuaries etc. Species of plants and animals together with all the components of their habitats are well protected and exploitations of biological resources as well as abiotic resources are strictly prohibited. Different aspects of biosphere reserves will be discussed at length in the succeeding section 24.2 of this chapter. It may be mentioned that India has 608 protected areas, 95 national parks, 500 wildlife sanctuaries, and 13 biosphere reserves of which 4 have been included in the International Network of Biosphere Reserves e.g. (1) Nilgiri Biosphere Reserve (recognized in 2000), (2) Gulf of Mannar Biosphere Reserve (in 2001), (3) Sundarban Biosphere Reserve (in 2001), and (4) Nanda Devi Biosphere Reserve (in 2004) have been recognized by Man and Biosphere Programme (MAB).

Coral Gardening

Coral gardening is a latest method to regenerate degraded coral ecosystem. There are 2 methods of cultivating corals in the laboratories and transplanting them in the degraded reefs to rejuvenate marine coral ecosystem.

1. Israeli Methds : minute coral fragments are cultured and generated in situ nursery. When these cultured coral colonies become adults, they are transplanted on degraded reefs. These transplanted colonies are able to adjust to new environmental conditions. It enables the generation of thousands of new coral colories and thus allows restoration of large degraded zone in short period of time.

Site example : this method has been successfully practiced in Eilat coral reefs of Israel which is world's northernmost coral reef and richest in biodiversity. Transplantation was carried out in 2007.

2, Japanese Method : involves culturing corals by developing corals from coral eggs to juvenile corals colories. This method is known as **sexual propagation.** This spawning method was successfully practiced in 2006 in one of the degraded coral reefs of Japan. By the year 2008 the transplantation resulted in the development of new coral colories.

(2) **Ex-Situ Conservation :** The method of ex-situ conservation of biodiversity simply means protection and conservation of plants and animals outside their natural native places. Such conservation is called **'off-site conservation'.** In fact, plants and animals, which face immediate extinction, are removed from their natural habitats and are brought up and maintained in other suitable areas managed by man. Such areas include botanical gardens, zoos, arboreta, genetic resource centers, culture collections, hatcheries etc. In order to restore genetic diversity of plants and animals the seeds and germplasms of rare and endangered species are stored in **'seed banks'** or **'germplasm banks'** to conserve genes of such species. Such storage centers are also called as **'gene banks'.**

24.2 BIOSPHERE RESERVE

The biosphere reserve programme is an effective method of the conservation of abiotic (land and water) and biodiversity of natural habitats. In fact biosphere reserves include the areas of terrestrial and coastal ecosystems wherein abiotic and biological resources (plants and animals) are managed and conserved in sustainable manner. In fact, biosphere reserves represent 'living laboratories' for the integrated management of land, water, plants, animals, and microbes therein. The programme of biospehre reserve is within the ambit of Man and Biosphere Programme (MAB) of the UNESCO. The concept of 'biosphere reserve refers to the protection and conservation of natural habitats, and plant and animal species therein with the following 3 goals :

- **Conservation Role,** conservation of biological diversity (say biodiversity),
- **Logistic Role,** setting up a well defined and identified international network of areas for field research and monitoring programmes and activities including training and information exchange in

accordance with MAB programme at international level, and

➤ **Development Role,** to associate concretely environmental protection and land resources with development (human & economic development) in a sustainable manner (fig. 24.1)

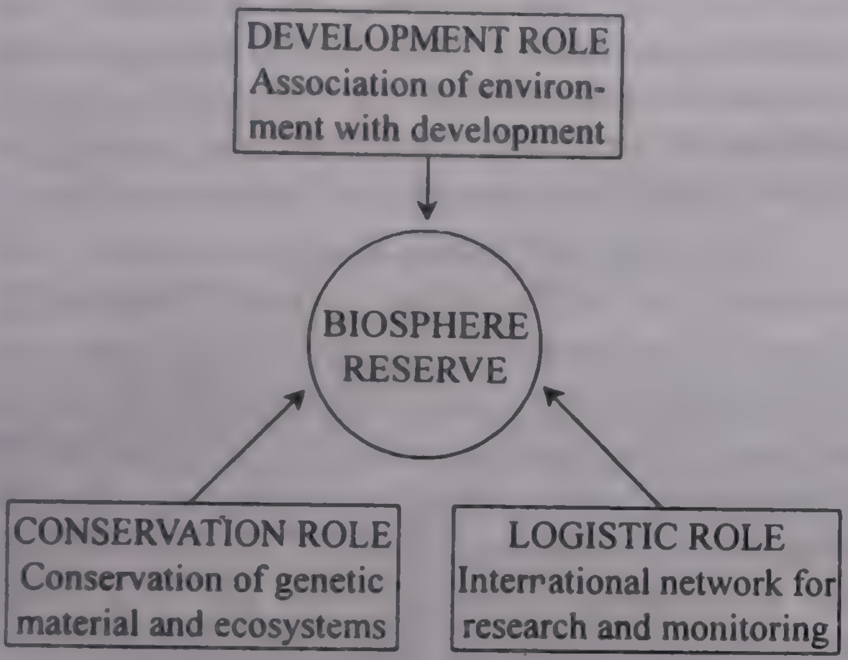

DEVELOPMENT ROLE
Association of environment with development
BIOSPHERE RESERVE
CONSERVATION ROLE
Conservation of genetic material and ecosystems
LOGISTIC ROLE
International network for research and monitoring

Fig. 24.1 : Major roles and goals of 'Biosphere Reserves' (after Michel Batisse, 1986-Nature and Resources, Vol, 22, No. 3, 1986).

Evolution of the Concept

The concept of **'biosphere reserve'** has its root in the conference on 'the Rational Use and Conservation of the Resources of the Biosphere' organized by MAB in 1968 wherein one of the recommendations was related to the **'utilization and preservation of genetic resources'**. The recommendations of the said conference proposed 'to make specific efforts to preserve representative samples of significant ecosystem, original habitats of domesticated plants and animals, and remnant populations of rare and endangered species, and for the 'preservation of natural areas and endangered species'.

In 1969 it was decided to have a 'co-ordinated world-wide network of national parks, biological reserves and other protected areas under Man and Biosphere Programme (MAB)'. Such areas were occasionally referred to as **'biosphere reserve'** but the real concept of 'biosphere reserve' was born in 1971 and first 'biosphere reserve' was identified in 1976. Since then the number of 'biosphere reserve' identified by MAB continued to increase and by the end of 1986 about 261 'biosphere reserves' were identified in 70 countries. Presently, (2005 A.D.) there are 499 biosphere reserves in 110 countries. Though there are 13 biosphere reserves in India but only 4 of them have been internationally recognized by MAB, namely (1) Niligiri biosphere reserve (in 2000), (2) Gulf of Mannar marine biosphere reserve (in 2001), (3) Sundarban biosphere reserve (in 2001), and (4) Nanda Devi biosphere reserve (in 2004).

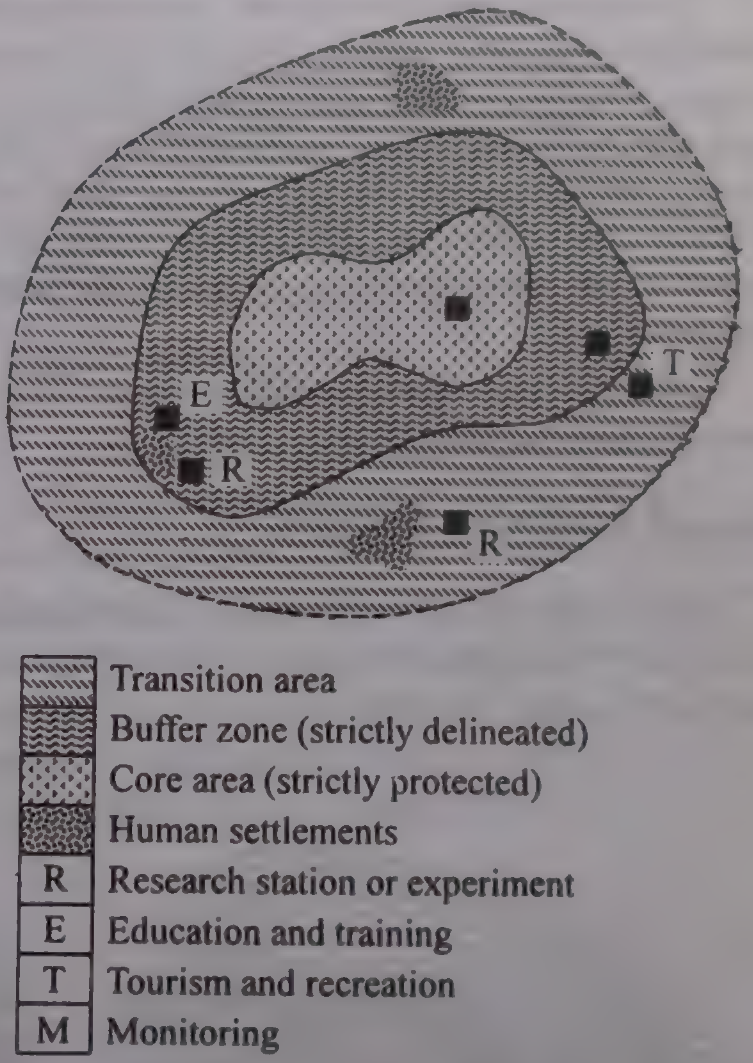

E
R
R
T
▨ Transition area
▦ Buffer zone (strictly delineated)
░ Core area (strictly protected)
▩ Human settlements
R Research station or experiment
E Education and training
T Tourism and recreation
M Monitoring

Fig. 24.2 : Schematic zonation of a biosphere reserve after Machel Batisse, 1986, (Nature and Resources, Vol 22, No. 2, 1986).

The MAB defined 'biosphere reserves' as basic logistic resources for research where experiments can be repeated in the same places over periods of time, as areas of education and training, and as essential components for the study of many projects under the programme'. It is apparent that the MAB in 1971 emphasized only two roles of the 'biosphere reserves' viz. conservation and logistic roles whereas development role was neighter defined nor highlighted. Fig. 24.1 represents three basic roles (logisatic role, conservation role and development role) of 'biosphere reserves' as referred to above.

A special 'task force' convened jointly by the UNESCO and UNEP (United Nations Environmental Programme) in 1974 prepared for the first time the objectives and a set of characteristics for 'biosphere reserves'. The major roles and objectives may be grouped in three categories as referred to in the beginning (1. conservation role, 2. logistic role, and 3. development role).

The following statements of the UNESCO in its 1981 publication clearly reveal the goals and objectives of 'biosphere reserve'.

'Biosphere reserves form an international network of protected areas in which an integrated concept of conservation is being developed, combining the preservation of ecological and genetic diversity with research, environmental monitoring, education and training. Biosphere reserves are selected as representative examples of the world's ecosystems'.

UNESCO, 1981 : MAB Information System : Biosphere Reserves, Compilation No. 2,313p.

Zoning of Biosphere Reserve

The 'task force' proposed a simple zoning pattern for 'biosphere reserve' in 1976 which comprised 3 zones as follows :

- strictly protected **'core area',**
- strictly dilineated **buffer zone,** and
- undelineated outer buffer zone or transition area (fig. 24.2).

The core area represents national park which is strictly protected and no one is allowed except the officials in this area. The buffer zone is strictly demarcated but can be used for regulated non-destructive activities on sustainable basis whereas the transition area is not delineated and is used for experimental research, traditional use, rehabilitation and other functions of the biosphere reserves.

A concept of **'cluster biosphere reserve'** was developed in 1977 during a joint USA-USSR symposium on Biosphere Reserve. 'This idea aims at accommodating the many situations where all the functions of biosphere reserves cannot be performed in contiguous areas where a regrouping and co-ordination of activities between several discrete areas is required. This is often the case when conservation in core areas has to be associated with integrated research and manipulative experimentation in other areas' (fig. 24.3) (Michel Batisse, 1986). Figure 24.3 represents an example of cluster biosphere reserve having two separate reserves but close to each other.

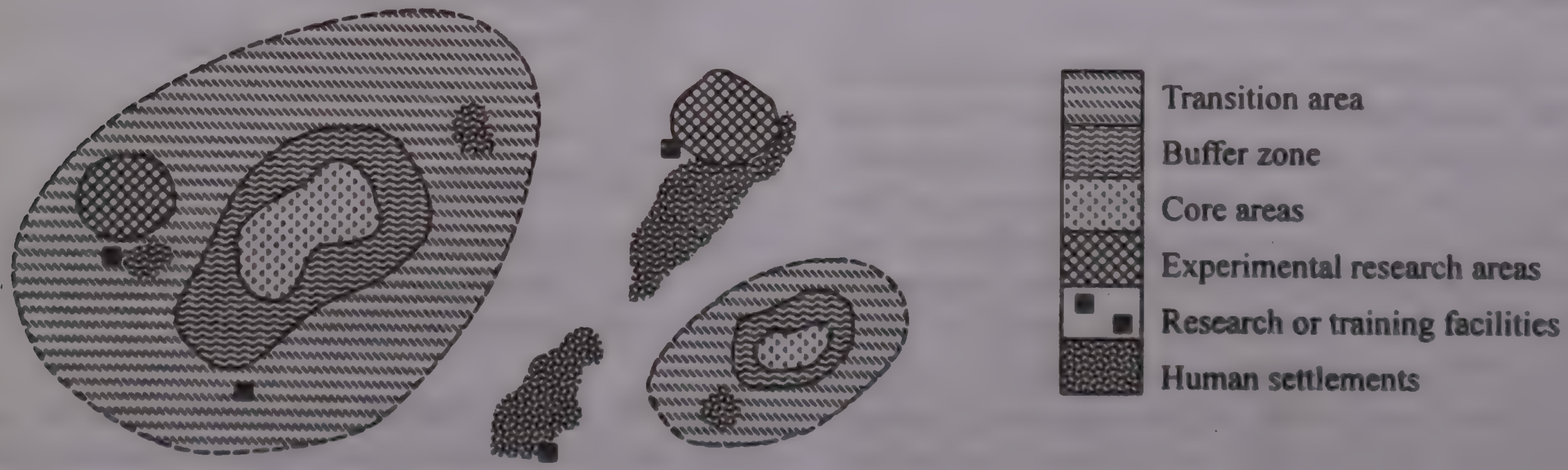


Fig. 24.3 : An example of cluster biosphere reserve with multiple functions as shown in fig. 24.2 (after Michel Batisse, 1986: Nature and Resources, Vol. 22, No. 2, 1986).

Michel Batisse (1986) has argued that a biosphere reserve must have the combined presence of its three major roles viz. conservation role, logistic role, and development role. He has forwarded the following yardstick for a real biosphere reserve :

'A biosphere reserve that does not have a protected core is not a true biosphere reserve. A national park that has no concern for the sustainable development of the surrounding areas is not a true biosphere reserve either. An area that combines conservation with research and education for ecosystem development can only become a proper biosphere reserve if it joins the international network of research, monitoring and information exchange'.

Michel Batisse, 1986 : Nature and
Resources, Vol 22, No. 2 1986

Functional Pattern of Biosphere Reserve

Michel Batisse (1986) has summarized the functional pattern of the biosphere reserves as prepared by the Action Plan and the Scientific Panel of the MAB as given below :

(1) Core Area

➤ 'Each biosphere reserve includes one or several **core areas** that are strictly protected according to well-defined conservation objective and consists of typical samples of natural or minimally disturbed ecosystems'. Normally, core areas of a biosphere reserve 'should be representative of the surrounding ecosystems where sustainable development is to be promoted'.

➤ 'The size and the shape of the core areas depend on the type of landscape in which they are located and on the conservation objectives they are intended to meet'. Core areas may be much larger in sparsely populated (human population) areas and relatively small in densely inhabited areas.

➤ 'Core areas may correspond to strict '**nature reserve**' or '**wild areas**', or national park, or to other types of strictly protected areas. Strict protection of core areas does not necessarily mean 'non-intervention' : they can be submitted to different types of protective management, depending on their specific conservation objectives and on the character and history of landscape. Core areas naturally exclude the presence of significant human settlements'. Besides non-destructive research, the other significant function of the core area is the environmental observation and monitoring.

➤ The core areas of the biosphere reserves are generally surrounded by a delineated buffer zone (fig 24.2). The core area and the buffer zone correspond to a single and autonomous administrative unit.

(2) Buffer Zone

'The buffer zone must have a clearly established legal or administrative status even when several administrative authorities are involved in its management. Only activities compatible with the protection of the core areas make take place. This includes in particular research (R), environmental education and training (E), as well as tourism and recreation (T) or other uses carried out in accordance

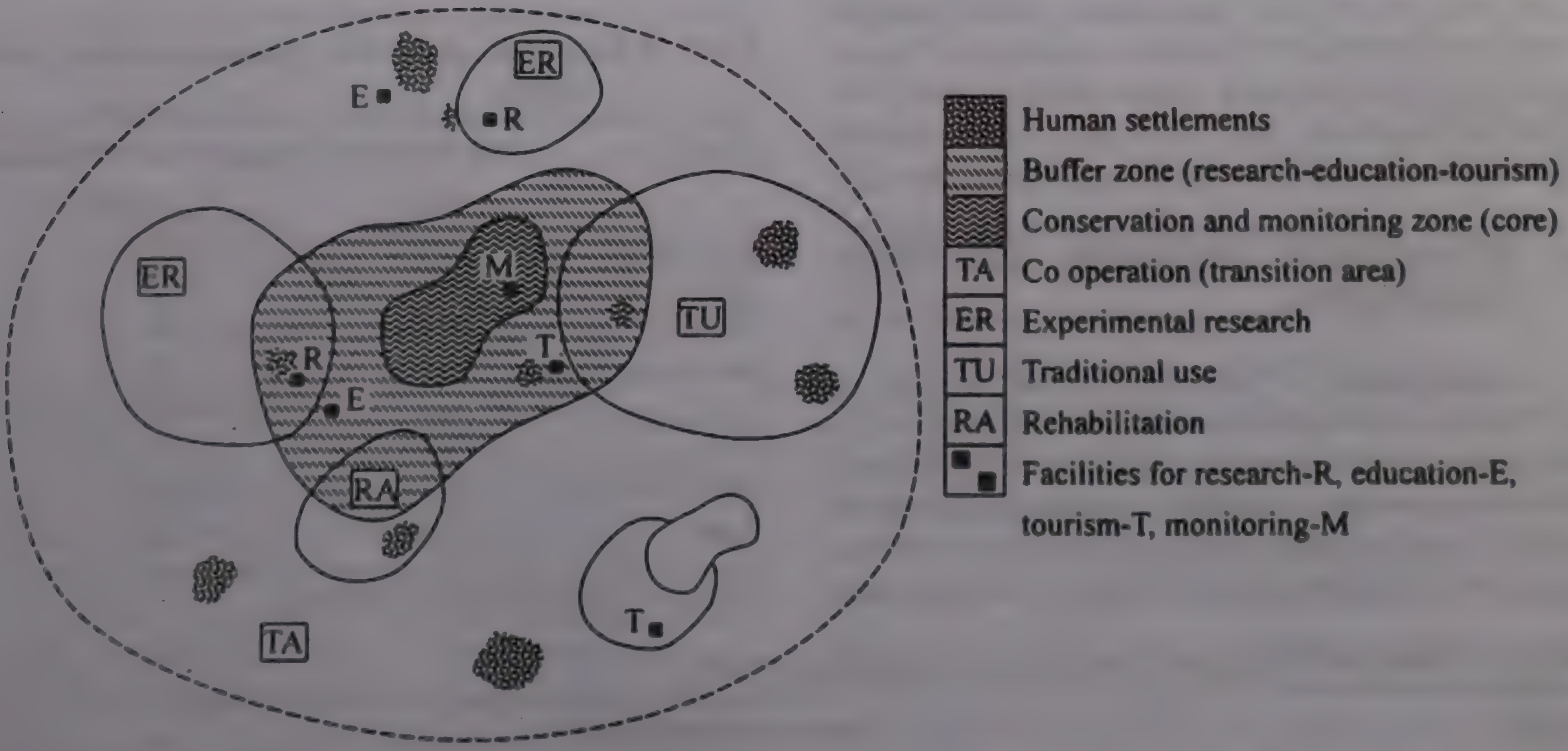

ER
E
R
ER
M
R
T
TU
E
RA
TA
T
Human settlements
Buffer zone (research-education-tourism)
Conservation and monitoring zone (core)
TA Co operation (transition area)
ER Experimental research
TU Traditional use
RA Rehabilitation
Facilities for research-R, education-E, tourism-T, monitoring-M

Fig. 24.4 : Schematic presentation of the functions of 'cluster biosphere reserve' (after Michel Batisse, 1986 : Nature and Resources, Vol. 22, No. 2)

with the management requirements and regulations. Besides its other functions, the buffer zone may well serve to protect areas of land that could be used to meet future needs for experimental research'.

(3) Transition Area

The transition area surrounding the buffer zone plays mainly development role such as cooperative activities between researchers, managers and local populations so as to ensure appropriate physical planning and sustainable resource development. Thus the transition zone works for the association of environment and development. This zone is biogeographic in character rather than administrative unit, so it covers larger and open areas. Since this zone is managed by different authorities and hence proper cooperation and coordination are required for the management and development programmes.

(4) Clustered Biosphere Reserve

'Partly within the buffer zone or entirely outside, a biosphere reserve may include any one or more combinations of the following types of associated areas, used to develop knowledge and skills for ecosystem use and management; (a) Areas suitable for experimental manipulation to develop, assess and demonstrate methods for sustainable development (experimental research areas ER); (b) Examples of harmonious landscape resulting from traditional patterns of land use (traditional use areas) (TU); and (c) Examples of modified or degraded ecosystems that are suitable for restoration to more natural conditions (rehabilitation areas) (RA)'. Fig 24.4 represents the different functions of 'clustered biosphere reserve'.

24.3 BIODIVERSITY (WILDLIFE) CONSERVATION IN INDIA

Management of wildlife is the branch of conservation which involves the protection, increase and maintenance of maximum number of wild/game animals in accordance with the supporting capacity of a particular natural habitat and the efforts to increase the productivity of the natural habitats. The success of the management of wild animals depends upon the environmental conditions of the natural habitats/ecosystems; the interests of the government, educationists, conservationists, planners and general public in the management programmes; proper understanding of and adherence to ecological principles; enactment of legislations by the government; forceful and effective implementation of laws and regulations regarding the wildlife.

Most of the Indian wild animals have now become endangered species because of rapid decrease in their populations. The destruction of natural habitats and important wild animals began during British rule when widespread hunting by British officials and Indian rulers resulted in large-scale killing of important animals. The unscrupulous and reckless hunting of game animals for recreation, food, hide, tusk, musk, horn, fur, wool etc. and rapid rate of deforestation due to agricultural expansion and industrial and urban growth have caused irreparable loss and damage to wildlife in India. Before attempting the wildlife management programme in India it is desirable to present a brief account of evaluation of wildlife status of the country.

Wildlife Status in India

Table 24.2 represents the status of species of plants and animals of different categories in India. The species categories include higher plants, mammals, breeding animals, reptiles, amphibians and fish.

Table 24.2 : Status of wildlife species in India (1992-2002)

Wildlife	Total known species	Number of threatened species
Higher plants	18,664	244
Mammals	390	88
Breeding birds	458	72
Reptiles	521	25
Amphibians	231	03
Fish	5,749	09

Source : World Resource Institute.

Table 24.3 : Rare and threatened species of vertebrates in India

Category	Approximate Number				
	Mammals	Aves	Reptiles	Amphibians	Total
Rare	—	02	—	—	02
Vulnerable	28	22	04	—	54

Endangered	29	21	16	01	67
Critical	03	08	—	—	11
Extinct	01	02	—	—	03
Insufficiently known	16	—	—	—	16
Total	77	55	20	01	153

Source : The Red Data Book of Indian Animals (1994), Zoological Survey of India.

The following are the critical species of animals : Brow-altered deer, yak, hispid hare (all are mammals); Christmas island frigate bird, Mrs. Hume's bartailed pheasant, Burmese peafowl, black necked crane, hooded crane, masked, finfoot, Jerson's coursers, forested spotted owlet (all are aves).

Extinct species include 'cheetah' (mammals), pinkheaded duck and mountain quail (birds).

Table 24.4 : Endemic and threatened species in India.

Faunal Groups	Total No.	Endemic Species		Threatened
		number	percentage	number
Mammals	372	38	10.21	77
Birds	1,228	69	5.61	55
Reptiles	446	214	47.98	22
Amphibians	204	110	53.92	01
Insects	53,430	16,214	30,34	—
Moluscs				
Land	1,511	878	58.01	—
Freshwater	212	89	41.98	—

Source : Zoological Survey of India, ENVIS News Letter, 4 (182), 1997

Threatened number of species of mammals, birds and reptiles is from Red Data Book, ZSI, 1994.

Unique animals of India include pigmy hog, black buck, lion-tailed macaque, Niligri tahr, golden langurs etc.

Typical animals of India are elephants, rhinocerous, deers (e.g. musk deer, barking deer, swamp deer-Bara singha, dancing deer-sambhar, Thamin and Ķashmir stag), antelopes (such as black buck, four-horned antelope-chausingha, Indian gazelle, chinkara, blue bull-nilgai), bison, wild buffalo, Himalayan ibex or wild goat, wild boar, wild ass, Nilgiri tahr, carnivourous animals (e.g. lion, tiger, leopard, stripped hyaena, wolf, black Himalayan bear, sloth bear), monkeys and apes (e.g. Nilgiri langur, lion-tailed monkeys, rhesus monkey, Hanuman monkey), Indian giant squirrels, porcupine, pangolin, birds (like peafowl, jungle fowl, partridge, quail, great Indian bustard, duck, pigeon, sandgrouse, storks, pelican, eagle, crane, owl, hornbill etc.), reptiles (crocodiles, alegators, lizards and several varieties of snakes) etc.

Management of Wildlife

Several measures have been adopted by the Union and State Governments for the conservation and preservation of wildlife in the country. These include enactment of laws, protection of endangered species and establishment of biosphere reserves, sanctuaries and national parks.

Several laws pertaining to the protection and conservation of wildlife have been formulated from time to time. The **Wild Birds and Animal Protection Act** was passed in the year **1887** but unfortunately it was repealed in 1912. **Forest Act** passed in the year **1927** aimed at the protection of game animals. The **Indian Board of Wildlife** was established in **1952** for the purpose of protection of wild animals. In subsequent year separate **Wildlife Boards** were established at state level. The new Wildlife Act provides more effective measures for wildlife management. The Wildlife Act has the following provisions :

- control and supervision of possession, trapping, shooting, hunting, chopping of wild animals whether alive or dead, the transport and export of wild animals and their products by the special forest staff (e.g. chief wildlife wardens and other authorized officials),
- protection to endangered and threatened animal species,
- graded protection to other wild animals according to the size of their population etc.

The establishment of Wildlife Institute at Dehradun (U.P.) has been a success in the wildlife management.

Efforts are being made to protect the following animals which have been enlisted as endangered and threatened species-black buck (Indian antelope), four-horned antelope (chausingha), white eyed buck, swamp deer, elephant, Indian gazelle (chinkara), musk deer, bharal, snow leopard, Great Indian Bustard, peafowl, serow, tahr, golden cat, pink headed duck, monitor lizard, water lizard, marsh crocodile, monal pheasant, chir pheasant, koklas pheasant, horned pheasant, python, lions, tigers etc.

It may be mentioned that India is a mega biodiversity country having rich biological communities of plants and animals. There are 12 mega biodiversity countries in the world including India. About 46,000 plant and 81,000 animal species have been identified and described. India joined **Convention on Biological Diversity** (CBD) in the year 1994, which has 3 major objectives as follows :

- conservation of biological diversity,
- sustainable use of components of biological diversity, and
- fare and equitable sharing of benefits arising out of utilization of genetic resources.

The following measures have been taken under the implementation of biodiversity conservation measures for the framework of CBD through national strategies, legislations and administrative instruments :

(1) National Biodiversity Strategy and Action Plan (NBSAP) Project : Under this scheme a National Policy and Action Strategy on Biological Diversity (NPASBD) has been formulated with the following activities :

- assessment and stocktaking of biodiversity related information at state level including distribution of endemic and endangered species and threats to specific habitats.
- emphasis on participation of decentralized state level planning sectors, interdisciplinary working groups, non-government organizations interested in the conservation of biodiversity.
- identification of the basic goals and thrust areas and to prepare action plans for management and conservation of biodiversity.
- to prepare detailed micro-level action plans at different levels under the framework of CBD and NBSAP.

(2) Biodiversity (Biological Diversity) Act : The Biodiversity Bill was passed in the year 2002 by the Lok Sobha. The Act envisages following goals :

- to protect and conserve rich biodiversity of the country,
- to protect the knowledge of biological communities having high medicinal value from their use by foreign individuals and organizations without seeking permission from India and without sharing the profits arising out of such use of biological treasure,
- to check and control biopiracy,
- setting up National Biodiversity Authority (NBA), State Biodiversity Boards (SBB), and Biodiversity Management Committees (BMC), and
- to promote conservation, sustainable use and documentation of biodiversity.

The Biodiversity Act has also made the following provisions for the use of Indian biodiversity :

- Prior permission for the use of Indian biological resources by foreign individuals and organizations from National Biodiversity Authority (NBA) is mandatory.
- The indigenous knowledge of India's biodiversity cannot be used by foreign individuals and organizations without formal permission from NBA.
- It is mandatory for any Indian individuals or entities to obtain formal permission from NBA for transferring findings of research related to Indian biological resources to any foreign individuals or organizations for commercial use of such knowledge/findings.
- It is mandatory for Indian industry to give prior intimation to the concerned SBB about obtaining any biological resource for commercial use. The SBB may deny the permission if the norms of conservation, sustainable use and benefit sharing are violated,

- Citizens (individuals), entities, local people, 'vaidyas' and 'hakims' (practicing in Ayurveda) are exempted from permission from NBA for the use of biological resources within the country for medicinal purposes, etc.

(3) Biosafety Protocol : India has signed the Biosafety Protocol known as Cartegena Protocol on Biosafety. This is the international regulatory framework for safe transfer, handling and use of Living Modified Organisms (LMOs). The protocol provides a number of tools and devices for promoting biosafety as given below :

- use of 'Precautionary Principles',
- application of Advanced Informed Agreement,
- Procedure for import of LMOs,
- Risk Assessment and Risk Management Framework,
- Capacity Building,
- Biosafety Clearing House Mechanism' etc.

The biosafety protocol was ratified by Indian Govt. on September 5, 2002.

The Govt. of India has made the following measures for the conservation and management of natural resources including forestry and wildlife (biodiversity), and sustainable uses of ecological resources :

- Conservation and management of biosphere reserves, wetlands, mangroves and coral reefs,
- Provisions for the establishment and maintenance of national parks and sanctuaries,
- Biodiversity conservation,
- Biosafety Protocol to check biopiracy,
- Genetic Engineering Approval Committee (GEAC),
- All India Coordinated Project on Taxonomy (AICPT),
- Medicinal Plants Conservation Areas (MPCAs) and Networks (MPCN),
- Forest Policy and Forest Conservation,
- Integrated Forest Protection Scheme,
- Joint Forest Management,
- Wildlife conservation, animal welfare etc.

Biosphere Reserves

India has also made biosphere reserves of terrestrial and coastal ecosystems within the framework of UNESCO's Man and Biosphere (MAB) programme with the goals of (1) conservation of biodiversity, (2) promoting research and training, and (3) monitoring and providing models for sustainable development. It is apparent that the biosphere reserves have to play 3 roles, namely (1) conservation role, (2) logistic role, and (3) development role.

In all 13 biosphere reserves have been identified and notified (table 24.5) by the Ministry of Environment and Forests (MEF) of Govt. of India, of which 4 have been recognized and approved by the International Coordinating Council (ICC) of MAB Programme of the UNESCO, such as (1) Nilgiri (2000), (2) Gulf of Mannar (2001), (3) Sundarbans (2001), and (4) Nanda Devi (2004).

Table 24.5 : Biosphere reserves in India

SL. No.	Name of the site	Geographical area (km^2)	Date of notification	Location
1.	Nilgiri	5,520	01.08.1986	Part of Wynad, Nagarhole, Bandipur and Madumalai, Nilampur, Silent Valley and Siruvani Hills (Tamil Nadu, Kerala and Karnatak)—Western Ghats
2.	Nanda Devi	5,860	18.01.1988	Part of Chamoli, Pithoragarh and Almora districts of Uttarakhand-West Himalayas
3.	Nokrek	820	01.09.1988	Part of Garo Hills (Meghalaya)—East Himalayas
4.	Manas	2,387	14.03.1989	Part of Kokrajhar, Bonaigaon, Barpeta, Nalbari, Kamrup and Darang districts (Assam)—East Himalayas
5.	Sunderbans	9,360	29.03.1989	Part of delta of Ganga and Brahmaputra rivers (West Bengal)—Gangetic Delta

6.	Gulf of Mannar	10,500	18.02.1989	Indian part of Gulf of Mannar between India and Sri Lanka (Tamil Nadu)-coasts, marine ecosystem
7.	Great Nicobar	885	06.01. 1989	Southern most islands of Andaman and Nicobar (A and N islands)-island ecosystem
8.	Simlipal	4,374	21.06.1994	Part of Mayurbharj district (Orissa)-Deccan Peninsula
9.	Dibru-Saikhowa	765	28.07.1997	Part of Dibrugarh and Tinsukia districts (Assam)-East Himalayas
10.	Dehang Debang	5,112	02.09.1998	Part of Siang and Debang Valley in Arunachal Paradesh-East Himalayas
11.	Pachmarhi	4,926	03.03.1999	Part of Betul, Hosangabad and Chindwara districts of Madhya Pradesh-Semi-Arid-Gujarat Rajputana
12.	Kanchanjunga	2,619	07.02.2000	Parts of Kanchanjunga Hills in Sikkim-East Himalayas
13.	Agasthyamalai	1,701	12.11.2001	Neyyar, Peppara and Shenduruny Wildlife Sanctuaries and their adjoining areas in Kerala

Wetlands, Mangroves and Corals

The Ramsar Convention has defined 'wetlands' as given below :

'Wetlands as areas of marsh fen, peatland or water, whether artificial or natural, permanent or temporary, with the water static or flowing, brackish or salt, including marine areas, depth of which does not exceed 6 meters such as mangroves, corals, estuaries, creeks, bays, sea grasses and lakes etc.'

The wetlands, managroves, and corals are of great ecological and economic significance but these are under severe threats of destruction and disappearance due to increasing human activities. Thus, the government launched a scheme of conservation and management of these fragile ecosystems in the year 1987. In all 24 wetlands, 33 mangroves, and 4 coral ecosystems have been identified for their conservation and management. The action plan for the conservation and management of wetlands, mangroves and corals include the following activities and objectives :

- ➤ survey and demarcation of fragile areas,
- ➤ protection of these ecosystems from human destructive activities,
- ➤ regeneration of disturbed areas,
- ➤ afforestation, regeneration, and restoration of degraded ecosystems,
- ➤ catchment area treatment,
- ➤. pollution control, weed control,
- ➤ wildlife conservation, sustainable fisheries development,
- ➤ environmental education and ecodevelopment activities through peoples' participation, etc.

National Parks

Any natural ecosystem of rich biodiversity and almost pristine habitats, may be declared national parks, provided that such natural area is of ecological, faunal, floral, geomorphological, and hydrological importance and needs protection and conservation. The following activities are strictly prohibited :

- ➤ hunting, killing or capturing of animals,
- ➤ deprivation of any wild animal of its habitat,
- ➤ destruction and collection of plants,
- ➤ use of weapons,
- ➤ grazing by any life stock other than wild animals of the concerned natinoal parks,
- ➤ alteration of boundaries of National Parks, etc.

At present there are 94 national parks of which States and UnionTerritories account for 85 and 9 national parks respectively (table 24.6).

Table 24.6 : National Parks in India

Sl. No.	Name	Area (km²)	Date of establishment	District	State
1	Kasu Brahmananda Reedy	1.42	1994	Hyderabad	Andhra Pradesh
2	Mahaveer Harina Vanasthali	14.59	1994	Hyderabad	Andhra Pradesh
3	Mrugavani	3.60	1994	Hyderabad	Andhra Pradesh
4	Sri Venkateswara	353.62	1989	Chittor & Cuddapah	Andhra Pradesh
5	Mouling	483.00	1986	Upper Siang	Arunachal Pradesh
6	Naldapha	1,985.23	1983	Changlang	Arunachal Pradesh
7	Dibru-Saikhowa	340.00	1999	Tinsukia & Dibrugarh	Assam
8	Kaziranga	471.71	1974	Golaghat & Nagaon	Assam
9	Manas	500.00	1990	Barpeta & Bongaigaon	Assam
10	Nameri	200.00	1998	Sonitpur	Assam
11	Orang	78.80	1999	Darrang & Sonitpur	Assam
12	Valmiki	335.65	1989	Pashchim Champaran	Bihar
13	Indravati	1,258.37	1981	Dantewada	Chhattishgarh
14	Kangerghati	200.00	1982	Kanker	Chhattishgarh
15	Sanjay	1,471.13	1981	Surguja, Koria	Chhattishgarh
16	Mollem	107.00	1978	North Goa	Goa
17	Bansda	23.99	1979	Valsad	Gujarat
18	Gir	258.71	1975	Junagadh	Gujarat
19	Marine (Gulf of Kachchh)	162.89	1980	Jamnagar	Gujarat
20	Blackbuck	34.08	1976	Bhavnagar	Gujarat
21	Kalesar	46.82	2003	Yamuna Nagar	Haryana
22	Sultanpur	1.43	1989	Gurgaon	Haryana
23	Great Himalayan	754.40	1984	Kullu	Himachal Pradesh
24	Pin Valley	675.00	1987	Lahul & Spiti	Himachal Pradesh
25	City Forest (Salim Ali)	9.07	1992	Srinagar	Jammu & Kashmir
26.	Dachigam	141.00	1981	Srinagar	Jammu & Kashmir
27	Hemis	4,100.00	1981	Ladakh	Jammu & Kashmir
28	Kistwar	400.00	1981	Doda	Jammu & Kashmir
29	Betla	231.67	1986	Palamau	Jharkhand
30	Anshi	250.00	1987	Uttar Kannada	Karnataka
31	Bandipur	874.20	1974	Chamarajanagar	Karnataka
32	Bannerghatta	104.27	1974	Bangalore	Karnataka
33	Kudremukh	600.32	1987	Chikmagalur & Dakshin Kannada	Karnataka
34	Nagarahole (Rajiv Gandhi)	643.39	1983	Mysore & Kodagu	Karnataka
35	Anamudi	7.5	2003	—	Kerala

36	Eravikulam	97.00	1978	Idukki	Kerala
37	Mathikettan Shola	12.82	2003	Idukki	Kerala
38	Pambadum Shola	1.318	2003	—	Kerala
39	Periyar	350.00	1982	Idukki	Kerala
40	Silent Valley	89.52	1984	Palakhad	Kerala
41	Bandhavgarh	448.85	1982	Umaria & Jabalpur	Madhya Pradesh
42	Fossil	0.27	1983	Mandla	Madhya Pradesh
43	Kanha	940.00	1955	Mandla & Balaghat	Madhya Pradesh
44	Madhav	375.22	1959	Shivpuri	Madhya Pradesh
45	Panna	542.67	1973	Panna & Chhatarpur	Madhya Pradesh
46	Pench (Priyadarshini)	292.85	1975	Seoni & Chhindwara	Madhya Pradesh
47	Sanjay	466.88	1981	Sidhi	Madhya Pradesh
48	Satpura	585.17	1981	Hoshangabad	Madhya Pradesh
49	Van Vihar	4.45	1979	Bhopal	Madhya Pradesh
50	Gugamal	361.28	1987	Amravati	Maharashtra
51	Nawegaon	133.88	1975	Bhandara & Gondia	Maharashtra
52	Pench	257.26	1975	Nagpur	Maharashtra
53	Sanjay Gandhi (Borivilli)	86.96	1983	Thane & Mumbai-Suburban	Maharashtra
54	Tadoba	116.55	1955	Chandrapur	Maharashtra
55	Keibul-Lamjao	40.00	1977	Bishnupur	Manipur
56	Balphakram	220.00	1986	South Garo Hills	Meghalaya
57	Nokrek	47.48	1986	East, West & South Garo Hills	Meghalaya
58	Murlen	200.00	1991	Champhai	Mizoram
59	Phawngpui Blue Mountain	50.00	1997	Chhimtuipui (E)	Mizoram
60	Intanki	202.02	1993	Dimapur	Nagaland
61	Bhitarkanika	145.00	1988	Kendrapara	Orissa
62	Simlipal	845.70	1986	Mayurbhanj	Orissa
63	Darrah	265.8	2003	Kota	Rajasthan
64	Desert	3,162.00	1980	Barmer & Jaisalmer	Rajasthan
65	Keoladeo Ghana	28.73	1981	Bharatpur	Rajasthan
66	Ranthambore	392.00	1980	Sawai Madhopur	Rajasthan
67	Sariska	273.80	1992	Alwar	Rajasthan
68	Khangchendzonga	1,784.00	1977	North & West Sikkim	Sikkim
69	Guindy	2.82	1976	Chennai	Tamil Nadu
70	Gulf of Mannar Marine	6.23	1980	Ramanathpuram & Tuticorin	Tamil Nadu
71	Indira Gandhi (Annamalai)	117.10	1989	Coimbator	Tamil Nadu
72	Mudumalai	103.24	1990	Nilgiris	Tamil Nadu
73	Mukurthi	78.46	1990	Nilgiris	Tamil Nadu

74	Corbett	520.82	1936	Nainital & Garhwal (Pauri)	Uttarakhand
75	Gangotri	1,552.00	1989	Uttarkashi	Uttarakhand
76	Govind	472.08	1990	Uttarkashi	Uttarakhand
77	Nanda Devi	630.00	1982	Chamoli	Uttarakhand
78	Rajaji	820.00	1983	Dehradun, Garhwal & Haridwar	Uttarakhand
79	Vaalley of Flowers	87.50	1982	Chamoli	Uttarakhand
80	Dudhwa	490.00	1977	Lakhimpur Kheri	Uttar Pradesh
81	Buxa	117.10	1992	Jalpaiguri	West Bengal
82	Gorumara	79.45	1994	Jalpaiguri	West Bengal
83	Neora Valley	88.00	1986	Darjeeling	West Bengal
84	Singhalila	78.60	1986	Darjeeling	West Bengal
85	Sunderbans	1,330.10	1984	North & South 24-Paraganas	West Bengal
Union Territories					
86	Campbell Bay	429.00	1992	Andaman	Andman & Nicobar Islands
87	Galathea	110.00	1992	Andman	Andaman & Nicobar Islands
88	Mahatama Gandhi Marine	281.50	1983	Andman	Andman & Nicobar Islands
89	Middle Button Island	0.64	1979	Andaman	Andaman & Nicobar Islands
90	Mount Harriett	46.62	1979	Andaman	Andaman & Nicobar Islands
91	North Button Island	0.44	1979	Andaman	Andaman & Nicobar Islands
92	Rani Jhansi Marine	256.14	1996	Andaman	Andman & Nicobar Islands
93	Saddle Peak	32.54	1979	Andaman	Andaman & Nicobar Islands
94	South Button Islands	0.03	1977	Andaman	Andaman & Nicobar Islands

Source : Websits, file ://A :\Untitled Document. htm

Wildlife Sanctuaries

There are 500 wildlife sanctuaries in the country where animals and habitats are protected and direct human use of any kind is strictly prohibited. The important Wild Life Sanctuaries are Bandipur Sanctuary (Karnataka),Bhadra Sanctuary (Chikmanglur, Karnataka), Bhimabandh Sanctuary (Monger, Bihar), Bori Sanctuary (Hosangabad, M.P.), Chandra Prabha Sanctuary (Varanasi, U.P. for Indian Lions), Dachigam Sanctuary (Jammu and Kashmir), Dalma Wild Sanctuary (Singhbhum, Jharkhand), Damp Wild Sanctuary (Aizwal, Mizoram), Dandeli Wild Life Sanctuary (Dharwar, Karnataka), Gandhi Sagar Wild Life Sanctuary (Mandsaur, M.P.), Warm Water Wild Life Sanctuary (Assam), Gautam Budha Wild Life Sancutary (Gaya, Jharkhand), Hazaribagh Wild Life Sanctuary (Hazaribagh, Jharkhand), Wild Life Sanctuary (Kohima, Nagaland), Jaldapara, Wild Life Sanctuary (Jalpaiguri, West Bengal), Wild Life Sanctuary (Adilabad, Andhra Pradesh), Kinnarsani Wild Life Santuary (Khamman, Andhra Pradesh), Manas Wild Life Sanctuary (Barpeta, Assam), Madumalai Wild Life Sanctuary (Nilgiri, Tamil Nadu), Someshwar Wild Life Sanctuary (South Kanara, Karnataka), Panchmarhi Wild

Life Sanctuary (Hosangabad, M.P.), Pakhal Wild Life Sanctuary (Warangal, Andhra Pradesh), Palamau Wild Life Sancutary (Daltonganj, Jharkhand), Periyar Wild Life (game) Sanctuary (Kerala), Ranathambhaur Wild Life Sanctuary (Sawai Madhopur, Rajasthan), Sharavathi Valley Wild Life Sanctuary (Shimoga, Karnataka), Shikari Devi Wild Life Santuary (Mandi, Himachal Pradesh), Simlipal Wild Life Sanctuary (Mayarbhanj, Orissa), Sonai Roopa Wild Life Sanctuary (Tejpur, Assam), Tansa Wild Life Sanctuary (Thane, Maharashtra), Tungbhadra Wild Life Sanctuary (Bellary, Karnataka) etc.

Table 24.7 : Spatial distribution of National Parks and Wildlife Sanctuaries (area in km^2)

		National Parks		Wildlife Sanctuaries		Total Area
S.No.	State	Number	Area	Number	Area	
1	Andhra Pradesh	4	3314.50	21	12530.09	15844.59
2	Arunachal Pradesh	2	2468.23	10	7114.45	9582.68
3	Assam	3	1173.71	13	939.88	2113.59
4	Bihar	2	567.32	21	3890.25	4457.57
5	Delhi	0	0.00	1	27.60	27.60
6	Goa	1	107.00	6	647.96	754.96
7	Gujarat	4	479.67	21	16422.71	16902.38
8	Haryana	1	1.43	9	278.32	279.75
9	Himachal Pradesh	2	1429.40	32	5736.85	7166.25
10	Jammu & Kashmir	4	4650.07	16	10172.15	14822.22
11	Karnataka	5	2472.18	20	3930.61	6402.79
12	Kerala	3	536.52	12	2143.36	2679.88
13	Madhya Pradesh	11	6474.69	35	10704.05	17178.74
14	Maharashtra	5	955.93	33	14387.78	15343.71
15	Manipur	2	81.80	1	184.85	266.65
16	Meghalaya	2	267.48	3	34.20	301.68
17	Mizoram	2	250.00	4	634.00	884.00
18	Nagaland	1	202.02	3	24.41	226.43
19	Orissa	2	990.00	18	6971.15	7961.85
20	Punjab	0	0	11	317.79	317.79
21	Rajasthan	4	3856.53	24	5712.83	9569.36
22	Sikkim	1	1784.00	5	265.10	2049.10
23	Tamil Nadu	5	307.85	20	2602.07	2909.92
24	Tripura	0	0	4	603.62	603.62
25	Uttar Pradesh	7	5410.82	29	7594.54	13005.36
26	West Bengal	5	1692.65	16	1103.48	2796.13
27	Andaman & Nicobar Islands	9	1157.14	94	372.13	1529.27
28	Chandigarh	0	0	2	26.01	26.01
29	Dadra & Nagar Haveli	0	0	0	0	0.00
30	Daman & Diu	0	0	1	2.18	2.18
31	Lakshadweep	0	0	0	0	0.00
32	Pondicherry	0	0	0	0	0.00
	Total	**87**	**40631.64**	**485**	**115374.42**	**156006.06**

Source : State of Forest Report, 1999

Among bird sanctuaries important are Ghana Bird Sanctuary (Bharatpur, Rajasthan), Ranganthittoo Bird Sanctuary (Karnataka), Vedanthangal Bird Sanctuary (Chingleput, Tamil Nadu), Malapatti Bird Sanctuary (Nellore, Andhra Pradesh) etc.

Tiger Reserves and Project Tiger

A national scheme known as **'Project Tiger'** has been launched in the country since 1973 by the Govt. of India with the following objectives :

- to ensure viable population of tiger in India through proper protection and management of tiger population,
- to ensure complete protection to tiger species in a few specially selected tiger reserves for scientific, ecological, economic, aesthetic, cultural and biological values and importance,
- to preserve the habitats and tigers therein as natural heritage for education and sight seeing, etc.

Tiger Census Method

There are 2 tiger census methods :

1. **Pug Mark Method** (unscientific)
2. **Camera Trap Method (scientific)**

The Pug Mark Method was applied to record the tiger census in 2001-2002 which yielded total number of tigers in India as 3642 of which 1500 tigers were in protected areas and 2142 tigers in outside protected areas. According to 2008 Tiger Census Report (on the basis of Canera Trap Method) total number of tigers was 1410, all in protected area.

Number of Tigers in India

	States	2001-2002 census	2008 census
1.	Tamil Nadu	60	76
2.	Maharashtra	238	103
3.	West Bengal	NA	NA
4.	Karnataka	401	290
5.	Bihar	76	10
6.	Assam	354	70
7.	Rajasthan	58	32
8.	M.P.	710	300
9.	U.P.	284	109
10.	Andhra Pradesh	192	95
11.	Mizoram	28	06
12.	Goa, Dam, Diu	05	0
13.	Orissa	173	45
14.	Kerala	71	46
15.	Chandigarh	227	26
16.	Jharkhand	34	NA
17.	Uttarakhand	251	178
18.	Meghalaya	47	0
19.	Nagaland	23	0
20.	Arunachal Pradesh	61	14
Total		3,642	1410*

Source : www.indiastat.com Tiger Census, 2008

NA = not assessed; *all in Protected areas

Reasons for decline of tiger population

- habitat degradation
- poaching
- reduced prey base
- confinement of tigers in protected areas

Suggestion for Tiger Conservation in Tiger Reserve

- provision of connectivity among individual tiger reserve,
- wildlife corridors for providing connectivity to tiger habitat,
- creation of invoilate areas,
- creation of buffer zone surrounding tiger reserve,
- involvement of local communities in tiger conservation, etc.

Initially there were 9 tiger reserves under the Porject tiger in the year 1973. The tiger reserve areas covered the geographical area of 16, 339 km^2 with total population of 268 tigers therein. At present there are 27 tiger reserves in India. Annamalais and Mudumali sanctuaries have been converted into tiger reserves (in 2006)

The basic principle of Project Tiger is to protect tigers in Tiger Reserves on the basis of **'core-buffer strategy'** wherein the core area is kept free from human and biotic disturbances, forestry operations, collection of forest produce of any kind, grazing, but the buffer zone becomes multiple use area i.e. buffer zone is managed to provide (1) habitats to such animals which are not allowed in the core areas or such wild animals which become surplus from core area, and (2) ecodevelopment inputs to surrounding villages, grazing, collection of firewood in regulated manner etc.

It may be mentioned that initially total tiger population was about 2000 (including 268 tigers in nine demarcated tiger reserves) in the year 1973 when the scheme of Project Tiger was launched. The total tiger population has subsequently increased to about 4000 (including 1498 tigers in 27 tiger reserves) by 2000 A.D. Table 24.7 displays the list of tiger reserves in India.

Table 24.7 : Tiger Reserves (under the scheme of Project Tiger) in India

Sl No.	Name of Tiger Reserves	Year of creation	Area (km^2)	State
1.	Bandipur	1973-74	866	Karnataka
1.	Nagarhole (extension)	1999-2000	643	Karnataka
2.	Corbett	1973-74	1,316	Uttar Pradesh
3.	Kanha	1973-74	1,945	Madhya Pradesh
4.	Manas	1973-74	2,840	Assam
5.	Melghat	1973-74	1,677	Maharashtra
6.	Palamau	1973-74	1,026	Jharkhand
7.	Ranthambhore	1973-74	1,334	Rajasthan
8.	Similipal	1973-74	2,750	Orissa
9.	Sunderbans	1973-74	2,585	West Bengal
10.	Periyar	1978-79	777	Kerala
11.	Sariska	1978-79	866	Rajasthan
12.	Buxa	1982-83	759	West Bengal
13.	Indravati	1982-83	2,799	Madhya Pradesh
14.	Nagarjunsagar	1982-83	3,568	Andhra Pradesh
15.	Namdapha	1982-83	1,985	Arunchal Pradesh
16.	Dudhwa	1987-88	811	Uttar Pradesh
	Katerniaghat (extension)	1999-2000	511	Uttar Pradesh
17.	Kalkad-Mundanthurai	1998-89	800	Tamil Nadu
18.	Valmiki	1989-90	840	Bihar
19.	Pench	1992-93	758	Madhya Pradesh
20.	Tadoba-Andheri	1993-94	620	Maharashtra
21.	Bandhavgarh	1993-94	1,162	Madhya Pradesh
22.	Panna	1994-95	542	Madhya Pradesh
23.	Dampha	1994-95	500	Mizoram
24.	Bhadra	1998-99	492	Karnataka
25.	Pench	1998-99	257	Maharashtra
26.	Pakhuri-Nameri	1999-2000	1,206	Arunchal Pradesh and Assam
27.	Bori, Satpura, Pachmarhi	1999-2000	1,486	Madhya Pradesh
28.	Annamalais	2005-2006	958	Kerala-Karnataka
29.	Mudumalai	2005-2006	321	Kerala-Karnataka

Project Elephant

The Govt. of India launched a scheme to protect the wild elephant population known as 'Project Elephant' on the line of 'Project Tiger' in the year 1992. The scheme has been implemented in 12 states of the country. The Project Elephant aims at the following :

- ➤ to assist the states having substantial number of wild elephants in protecting them.
- ➤ to ensure viable populations of elephants in their natural habitats.
- ➤ to strengthen effective measures of protection of wild elephants from poachers.
- ➤ to develop scientific and planned management programmes for the conservation of natural habitats of elephants.
- ➤ to restore and strengthen migratory routes of wild animals.
- ➤ to promote measures of mitigation of man-elephant conflicts in the peripheral areas of natural habitats of elephants.
- ➤ to promote researches on different aspects of conservation of elephants and their habitats,
- ➤ to promote environmental education and public awarness about wildlife importance and conservation.
- ➤ to educate and train field staff, mahouts and veterinarians.

The Project Elephant has been effectively implemented in 12 states, namely Arunachal Pradesh, Assam, Meghalaya, Nagaland, West Bengal, Jharkhand, Orissa, Andhra Pradesh, Karnataka, Tamil Nadu, Kerala, and Uttarakhand. By the year 2002, 14 **'elephant reserves'** were set up as follows :

1. Singhbhum (Jharkhand)
2. Garo Hills (Meghalaya)
3. Mayurbhanj (Orissa)
4. Mahanadai (Orissa)
5. Sambalpur (Orissa)
6. Eastern Doars (West Bengal)
7. Mayurjhama (West Bengal)
8. Wayand (Kerala)
9. Nilambur (Kerala)
10. Anamudy (Kerala)
11. Periyar (Kerala)
12. Kumeng (Arunachal Pradesh)
13. Mysore (Karnataka)
14. Shiwalik (Uttarakhand)

Under the scheme of Project Elephant regulai elephant census is carried out to monitor the elephant population. Besides, refresher courses foi elephant veterinarians are also arranged so that the health conditons of elephants are taken care of..

Project Snow Leopard in India

Recently India has launched, the scheme of **'roject snow leopard'** in the tune of Project Tiger, Project Elephant, Project Rhino etc. The following are the salient features :

- total number of snow leopard in India = 750
- aims → to save and conserve high altitude population of leopard and their habitats through participatory policies and actions i.e. participation of local people.
- covers the areas of Himalayan altitudes covering the following :
  - ➤ Jammu and Kashmir
  - ➤ Himachal Pradesh
  - ➤ Uttarakhand
  - ➤ Arunchal Pradesh
  - ➤ Sikkim
- Approach of conservation adapted:
  - ➤ landscape level approach to wildlife conservation,
  - ➤ by developing scientific framework for comprehensive surveys,
  - ➤ by rationalizing the existing protected area network,
  - ➤ by improving protected area management, etc.
- methods of conservation
  - ➤ promoting a knowledge based adaptive conservation framework,
  - ➤ involving the local communities, who share the snow leopard range, in conservation effort.
- Need of this project
  - ➤ because of very low population of snow leopard in India.
  - ➤ man-animal conflict.
  - ➤ hostile landscape of their areas and hence harsh environmental conditions.
- snow leopards have been included in the category of **Recovery Programme.**

  'Integrated Development of Wildlife Habitats'

25

ENVIRONMENTAL DEGRADATION AND POLLUTION IN INDIA

Rapid rate of industrialization, urbanization, agricultural development and above all population growth have put great pressure on the use of land, water and vegetation resulting into degradation of lands as wastelands through rapacious exploitation of forest resources and consequent accelerated rate of soil erosion, degradation of surface water, both rivers and lakes, because of discharge of immense volume of untreated polluted sewage and effluents coming out of industrial installations and urban centres into our rivers, acute air pollution in the urban agglomerations since 1950.

25.1 POPULATION GROWTH AND ENVIRONMENT

Rapid rate of increase in population has been held responsible as one of the most significant factors of environmental degradation because everincreasing population puts greater demands on the use of limited resources of a country. In fact, industrial expansion, urban growth, agricultural development, increase in means of transport and communication etc. are the outcome of population growth because the people must generate better facilities for their existence and better life. The development of scientific techniques and advanced technologies has to be made in order to save the humanity from hunger and natural calamity and disaster. Consequently, the rate of exploitation of natural resources increases more rapidly than the rate of population growth which causes depletion and exhaustion of certain valuable non-renewable resources. The world scenario of population growth and environmental degradation has been discussed in chapter 20 of this book. This section deals with the scenario of population growth in Indian context.

As already stated, unproportional growth (in relation to natural resources) in human population puts additional pressure on natural resources to sustain population which causes environmental degradation. Total population multiplied by more than 3.5 times within last one hundred years i.e. 1901-1991, 4 times from 1911 to 2001 and 5 times from 1901 to 2011 A.D. (table 25.1) which simply means that the pressure on India's natural resources has increased about five fold. Consequently, net area sown had to be increased from 118.75 million hectares in 1950-51 to 142.81 million hectares in 1994-95 (table 25.8) but decreased to 141.89 million hectares in 2005-06. It may be mentioned that this increase in net sown area consequent upon increased demand of food and other items due to phenomenal increase in population resulted in decrease in forest cover, substantial increase in irrigational facilities and irrigated areas (gross irrigated area increased from 22.5 million hectares in 1950-51 to 71.56 million hectares in 1995-96 (table 25.7), increased use of agrochemicals (nitrogen, phosphate and potash), increased use of pesticides in order to control crop diseases but to pollute soils, water and food chain, increase in the use of fungicides, herbicides etc.

Table 25.1 Growth of population in India

Census Year	Total population (millions)	Rural population		Urban population	
		Total (millions)	Percentage	Total (millions)	Percentage
1901	238.39	212.54	89.16	25.85	10.84
1911	252.09	226.15	89.79	28.08	10.21
1921	251.32	223.23	88.82	28.06	11.18
1931	278.97	245.52	88.00	33.45	12.00
1941	318.66	274.50	86.14	44.15	13.86
1951	361.08	298.64	82.70	62.44	17.30
1961	439.23	360.29	82.03	78.93	17.97
1971	548.15	439.04	80.10	109.11	19.90
1981	683.23	523.86	76.66	159.46	23.34
1991	846.30	628.69	74.29	217.61	25.71
2001	1027.00	739.40	72.00	287.60	28.00
2011	1210.19	833.09	68.84	377.09	31.16

Source : Gensus of India

It is pertinent to mention that the flight of population from rural areas to urban areas results in concentration of huge population in limited space forming big cities, metropolis and megalopolis only to stress the urban environment, by increasing number of squatter settlements and slum dwellers, causing air and water pollution beyond permissible limit etc. It is evident from table 25.1 that urban population increased from 25.85 million (10.84 per cent of the total population) in 1901 to 287.6 million (28 percent of total population) in 2001, and 377 million in 2011. This has resulted in severe air pollution in big cities of India like Delhi, Mumbai, Kolkata, Kanpur, Pune etc. The Yamuna river has become a sewer in Delhi due to discharge of enormous pollution load in the river (see section 25.6). It is also evident from table 25.1 that rural population decreased by about 17 per cent while urban population incresed by 17 percent from 1901 to 2001. It is estimated that by the year 2016 about 34 per cent of the total country's population will be housed in urban areas as the total urban population is expected to rise from 254.2 million in 1996 to 425.6 million against total India's population of 1,263.54 million in 2016 A.D. If pollution control measures are not adopted and population growth is not checked the urban environment of the country will be polluted beyond imagination in the 21st century. Almost all of the million cities of India are heavily polluted.

Increase in population results in corresponding increase in means of transportation in rural areas in general and in urban areas in particular. Increase in the number of automobiles consequent upon phenomenal increase in urban population increases pollution load (air pollution, water pollution, solid waste pollution etc.) in urban areas. Vehicle population in India increased from 0.306 million in 1950-51 to 34.216 million in 1995-96 (table 25.2). The number of automobiles in the metropolitan cities inorder to cater the increased demand of transport consequent upon rapid rate of growth of their urban population registered phenomenal increase from 1982 to 1996 (table 25.3)

Table 25.2 : Growth of vehicle population in India, (millions)

Year	Two-wheeler	Car, Jeep, and . taxi etc	buses	goods vehicles	others	Total all vehicles
1951	0.027	0.159	0.034	0.082	0.004	0.306
1971	0.576	0.682	0.094	0.343	0.170	1.865
1991	14.200	2.954	0.331	1.356	2.533	21.374
2001	38.556	7.058	0.634	2.948	5.795	54.991
2006	64.743	11.526	0.992	4.436	7.921	89.618

The total number of vehicles increased about 7 fold from 1980-81 to 1995-96 (table 25.2), two wheeler vehicles increased by more than 10 times while car, jeep and taxi increased by about 4 times from 1980-81 to 1995-96. It may be menntioned that most of the two and four wheelers except buses and trucks are used in the urban centres to cause serious air pollution. The metropolitan cities are the worst sufferers of air pollution caused by phenomenal increase in vehicle population during 1982-1996 (table 25.3). Delhi is the worst sufferer from this stand point as the vehicle population increased from 0.593 million in 1982 to 2.63 million in 1996 which is more than four fold increase.

Table 25.3 : Vehicle population in major metropolitan cities (millions)

Year	Bangalore	Kolkata	Chennai	Delhi	Hyderabad	Mumbai
1982	0.191	NA	0.141	0.593	0.110	0.339
1985	0.278	0.311	0.166	0.841	0.172	0.441
1988	0.411	0.397	0.420	1.284	0.442	0.557
1991	0.577	0.475	0.544	1.813	0.443	0.628
1994	0.716	0.545	0.689	2.239	0.543	0.608
1995	0.798	0.561	0.768	2.432	0.557	0.667
1996	0.900	NA	0.812	2.630	NA	0.724
	2.88 (in 2007)	1.05 (in 2007)	3.242 (in 2009)	6.000 (in 2011)	2.326 (in 2011)	1.938 (in 2011)

It is the quality and not the quantity of population which matters more in the national development and education is one of the important indicators of population quality. It may be mentioned that 'India's literacy rate is growing and the gender gap is closing (table 25.4). Educated women have less fertility rate than illiterate women and hence contribute in restricting the population growth and indirectly help in minimizing environmental degradation (table 25.5). According to 1991 census it has become obvious that fertility rate of women decreases with increasing level of women education as the rate dropped from 5.1 for the women having no education to 2.1 for the women having higher education (table 25.5).

Table 25.4 : Growth of literacy rate in India, 1931-2011

Year	Total literacy rate (percentage of total population)	Male literacy rate (percentage of male population)	Female literacy rate (percentage of female population)
1931	9	16	2
1951	18	27	5
1961	28	40	5
1971	35	46	22
1981	44	57	30
1991	52	64	39
2001	65	75	53
2011	74	82	65

Source : The Citizen's Fifth Report, 1999, CSE, New Delhi, Vol. I, p. 269.

Table 25.5 : Fertility rate in India (percentage) : Average national fertility rate = 2.72 children per woman.

Women with no education	5.1
Women with primary education	4.5
Women with upper primary education	4.0
Women with secondary education	3.1
Women with higher education	2.1

Source : The Citizen's Fifth Report, 1999, CSE, New Delhi, Vol.I, p. 268.

25.2 AGRICULTURAL DEVELOPMENT AND ENVIRONMENTAL DEGRADATION

Agricultural development in terms of expansion of agricultural land through major land use changes, increase in agricultural productivity and net agricultural production through the application of modern scientific techniques and advanced technologies, increased production and use of **agrochemicals** (chemical fertilizers and pesticides), expansion in irrigational facilities and irrigated areas, development of high-yielding varieties of seeds in order to meet the food requirement of ever increasing population of the country has no doubt solved the food problem of India but has also created and is creating hazardous environmental problems of serious concern. Though the pace of agricultural development has to be maintained if we do not want to let the teeming millions die of hunger but environmental degradation should not be allowed to continue due to agricultural development because it would also cause irreparable loss to human society.

Table 25.6 : Land use in India, 1950-51 to 1994-95 (million hectares)

Geographical area	328.73			
	1950-51	1970-71	1990-91	2005-06
A. Reporting area for land utilization (1 to 5)	284.32	303.76	304.86	305.27
1. Forests	40.48	63.91	67.80	69.79
2. Not available for cultivation				
(i) area under non-agricultural uses	9.36	16.48	21.09	25.03

(ii) barren and unculturable land	38.16	28.16	19.39	17.47
3. Other uncultivated land excluding fallow land				
(i) permanent pastures and other grazing lands	6.68	13.26	11.40	10.41
(ii) land under miscellaneous tree crops and groves not included in net area sown	19.83	4.30	3.82	3.38
(iii) culturable waste	22.94	17.50	15.00	13.12
4. Fallow lands				
(i) fallow land other than current fallows	17.44	8.76	9.66	10.57
(ii) current fallows	10.68	11.12	13.70	13.67
5. Net area sown	118.75	140.27	143.00	141.89

There has been substantial increase in agricultural land since 1950 in order to increase agricultural production. It may be mentioned that the land area under forests as shown in table 25.6 does not depict clear picture because it also includes areas under plantation. The net area sown continuously increased from 118.75 million hectares in 1950-51 to 142.81 million hectares in 1994-95 but slightly decreased to 142.21 million hectares in 1995-96 and 141.89 million hactares in 2005-06.

Expansion in agricultural land necessitated increase in irrigational facilities and irrigated land and use of agrochemicals (chemical fertilizers and pesticides) to increase agricultural production. Consequently, net irrigated area increased from 20.85 million hectares in 1950-51 to 52.99 million hectares in 1994-95, 53.51 million hectarea in 1995-96 and 60.19 million hactares in 2005-06, while gross irrigated area increased from 22.56 million hectares in 1950-51 to 70.63 million hectares in 1994-95 and 71.51 million hectares in 1995-96 (table 25.7).

Table 25.7 : Net and gross irrigated area, 1950-51 to 1995-96 (million hectares)

Year	Net irrigated area	gross irrigated area
1950-51	20.85	22.56
1960-61	24.66	27.98
1970-71	31.10	38.19
1980-81	38.72	49.73
1990-91	46.70	61.85
1994-95	52.99	70.63
1995-96	53.51	71.51
2005-06	60.19	—

Due to a host of causal factors mainly deforestation, accelerated soil erosion and excessive irrigation, natural hazards like floods, land is degraded and wasteland is increasing. By the end of 20th century the country had 129.57 million hectares of wasteland of which 35.85 million hectares were degraded forest area and 93.66 million hectares of degraded non-forest area including saline/alkaline area, wind and water eroded areas. The land has been rendered wasteland due to a host of anthropogenic and natural factors, viz. wind and water erosion (desertification due to deforestation and excessive grazing in the dry land area, accelerated soil erosion consequent upon deforestation and overgrazing), water logging (due to canal irrigation), ravine and gully erosion (due to deforestation and overgrazing and faulty cultivation of gullied and already ravinated land), shifting cultivation, riparian erosion by rivers, flooding of agricultural and non-agricultural land due to increase in the frequency and dimension of floods caused by anthropogenic activities (mainly deforestation and related accelerated soil erosion and siltation of river valleys) etc. The adverse effects of major land use changes like shifting cultivation and replacement of forest cover by fruit orchards will be discussed in the section 'deforestation and environmental degradation'.

Increased use of agrochemicals (chemical fertilizers) and pesticides to boost agricultural productivity and production has immense adverse effects on land and water resources of the country. Agricultural land has been extensively polluted through non-point pollution of agrochemicals. For example, Haryana state is the worst sufferer. Agricultural runoff containing chemicals residue from the heavily fertilized agricultural fields of Haryana finally reaches Delhi to pollute the Yamuna. The soil salinity has reached a new high in Haryana. The increasing demand of agrochemicals has also put enormous pressure on home production of these chemicals which have increased many fold from 1951 to 1997 (table 25.8). The home production of nitrogen and phosphate fertilizers together has increased from 0.04 million tonnes in 1951-52 to 11.31 million tonnes in 1996-97. The deficit of required chemical fertilizer is met with import. The combined import of nitrogen, phosphate and potash fertilizers increased from 0.057 million tonnes in 1951-52 to 2.05 million tonnes in 1996-97 while the consumption of these fertilizers increased from 0.08 million tonnes in 1951-52 to 14.31 million tonnes in 1996-97 (table 25.8).

Table 25.8 : Production, import and consumption of chemical fertilizers (nitrogen, phosphate and potash) in India, 1951-52 to 1996-97 (million tonnes)

Year	Production	Import	Consumption
1951-52	0.04	0.057	0.08
1960-61	0.26	0.41	0.29
1970-71	10.06	0.623	4.38
1980-81	3.06	2.75	5.52
1990-91	9.13	2.76	12.55
1994-95	10.60	2.13	13.56
1995-96	11.48	4.11	13.88
1996-97	11.31	2.05	14.31

Source : The Citizen's Fifth Report, Vol II, 1999, CSE, New Delhi, based on Anon 1997. Note : No home production of potash.

Green revolution necessitated greater use of pesticides (including insecticide, fungicide, weedicide, rodenticide, fumigant, plant growth regulator) to control plant diseases to ensure good harvest of foodgrains, fruits, vegetables etc. Consequently, the production of pesticides increased from 2,836 tonnes per annum in 1955-56 to 1,02,240 tonnes in 1997-98 while the home consumption of pesticides far exceeded the home production (and hence necessitated import to meet the deficit) as their consumption increased from 2.35 million tonnes in 1955-56 to 52 million tonnes in 1997-98. The unchecked use of chemical fertilizers and pesticides has degraded our soils, agricultural runoff has polluted surface water (tanks, ponds, lakes and rivers) and groundwater, the chemicals have reached food chains and have adversely affected human health and wealth.

20.3 DEFORESTATION AND ENVIRONMENTAL DEGRADATION IN INDIA

Forests are invaluable property of a nation because they provide raw materials to modern industries, timber for building purposes; habitats for numerous types of animals and micro-organisms; good friable and nutrient-rich soils having high content of organic matter; offer protection to soils by binding the soils through the network of their roots and by protecting the soils from direct impact of falling raindrops; they encourage and increase inflitration of rainwater and thus allow maximum recharge of groundwater resources; minimize surface runoff and hence reduce the frequency, intensity and dimension of floods; they help in increasing precipitation; they are natural 'sink' of carbon dioxide because they use carbon dioxide to prepare their food during the process of photosynthesis; they provide firewood to millions of people all over the world, and food and shelter to innumerable humans and animals, In fact, forests are 'life line' of a nation because prosperity and welfare of the society directly depends on sound and healthy forest cover of the nation concerned. Forests are main component of the biotic components of the natural environmental system and the stability of the environment and ecosystem/ecological balance largely depends on the status of the forests of the region concerned.

The aforesaid mentioned positive sides of forest covers have been ignored and the forests have been shabbily treated not only in India but the world over. It may be mentioned that forest monitoring data in the country are not reliable as these vary due to different reporting sources and agencies. The major forest data monitoring agencies are Food and Agricultural Organization (FAO) of the U.N.O. and the Ministry of Environment and Forest (MEF) of the Govt. of India through its two-yearly report named the State of Forest Report (since 1987) published by the Dehra Dune-based Forest Survey of India (FSI). It is also to note that areas under natural forests and plantations are very often amalgamated but these should be separated to understand clear picture of natural dense forest cover which consists of undisturbed, pristine forest cover having immense biodiversity and frontier forests.

Natural forests of India are classified under 3 categories viz. **dense forests** (which have tree crown density of 40 per cent or more), **open forests** (also classed as **degraded forests,** have tree crown density between 10-40 per cent) and **scrub forests** (which have tree crown density of less than 10 per cent, these are not included in the total forest cover data). Environmentalists and forest managers need actual ground data of a natural forests for their better conservation and management while industries requiring wood for the manufacturing of different goods ranging from plywood and rayon to pulp and paper, need the data of the extent of plantations. One should be, therefore, cautious about the break up of area under forest cover. Generally, forest area data include area covered with trees (dense and open forests), scrubs, non-forest land, plantations etc., whereas forest cover includes area covered with trees only.

Table 25.9 : Forest cover (km²)

		2005	2007	Change
1.	Very dense forest	83,472	83.510	+38
2.	Moderately dense forest	319,948	319,012	–936
3.	Open forest	286,751	288,377	+1626
	Total	**690,171**	**690,899**	**+728**
4.	Scrub forest	41,286	41,525	+239

Source : India State of the Forest Report, 2009.

The perusal of table 25.9 denotes that very dense forest cover (tree crown density of more than 70 percent of the area) increased by 38km² from 2005 to 2007 while moderately dense forest (tree crown density from 40 to 70 percent) decreased by 936 km² from 2005 to 2007. Open forest (tree crown density 10 to 40 percent) increased by 1626 km^2 from 2005 to 2007.

Forest cover and tree cover in India (2009) are 22.26 and 2.99 percent of geographical area respectively. Thus, forest cover + tree cover combined together represent 25.25 percent of geographical area of India.

Rate of Deforestation

It is interesting to note that while plantions are increasing and are added to the forest area (government owned land area kept for forestry purposes), the forest cover (natural forest area) is contracting in size. The area covered with trees (very dense forests + moderately dense forests + open forests + degraded forests + mangroves) declined by 0.55 million hectares from 1995 (63.89 million hectares) to 1997 (63.34 million hectares), thus registering annual loss of 0.27 million hectares of forest cover. The situation improved from the year 2005 to 2007 (table 25.9) when total forest cover (dense forests + open forests) registered an increase of 728 km^2 area. The combined total of dense forests, open forests and scrub forests registered an increase of 967 km^2 area from 2005 (731, 457 km^2) to 2007 (732, 424 km^2)

Pristine Forest Cover

Pristine forest cover refers to such natural dense forest cover which is undisturbed and unlogged and has immense biodiversity. As per FAO report pristine natural dense forest cover was 14.96 million hectares in 1980. This pristine forest cover, thus, accounted for only 25 per cent of the total natural forest cover and only 4.6 per cent of the geographical area (328.73 million hectares) of India. The break up of pristine dense forest area in 1980 was as follows—(i) undisturbed forests, 5.991 mha, (ii) unlogged forest because of inaccessibility, 2.19 mha, and (iii) protected area, 6.779 mha. There is gradual loss even of dense natural forest in tiger reserves as this area declined from 1.11 mha in 1983 to 1.09 mha in 1989. Thus, not more than 11.66 mha of forests, or about 3.5 per cent of country's land area (328.73 mha), were in an undisturbed pristine state by 1995 (Anil Agrawal, et. al, 1999).

Forest Loss due to Fruit Orchards

Replacement of forest cover by food crops and fruit orchards also degrades the forest environment. Replacement of forest cover by apple cultivation in the hill districts of Himachal Pradesh, India or say practicing of monoculture in place of biotic diversity of forest ecosystem tells the story of adverse impact on the environment of the Himalayas. Apple cultivation has enormously increased in Himachal Pradesh in the post-independence era at the cost of rich natural vegetation of the Himalayas (falling in Himachal Pradesh). It may be stated that at present Himachal Pradesh produces about one third of the total apple production of India. Though the apple cultivation has increased the economic prosperity of the state to some extent but it has swallowed large area of natural forest covers. Lured by the economic gain of apple cultivation the farmers removed the forest at accelerated pace and started apple plantation. Apple cultivation results in complete removal of all natural vegetations because no other plant is desirable in apple fields. Normally, the apple plants start yielding fruits after 5 to 7 years of their plantation. During this period of growth of apple plants the open areas between them are devoted to potato cultivation which allows more and more soils to be eroded because potato plants are totally unable to bind the soils and to protect them from the high intensity rainfall. This results in the removal of fertile and valuable top-soil layer through soil erosion caused by rainsplash, surface and rillwash. Secondly, monoculture in the form of apple cultivation also causes ecological imbalance because most of the plants and animals and micro-organisms are destroyed. Thirdly, a lot of wood is required for the packing of apples. This aspect places further pressure on forest and consequently more and more trees are cut in order to manufacture wooden boxes for the packing of apples and their export. According to an estimate wood of about 7 to 10 hectares of forests is required for the packing of apples of one hectare of land. Fourthly, huge amount of fungicide (chemicals to destroy pests) is used to save the apples from the dangerous disease of scab. This toxic dangerous chemical finds its way to surrounding areas and streams via surface runoff, rills and rivulets and thus contaminates the waters of the hills as well as of the plains.

Shifting or **jhuming cultivation** is also a major cause of forest loss in the hilly and mountainous areas of the country.

Plantations

In order to enrich the depleted forest areas of the country, to meet the need of the society in different forms, planatation on deforested degraded land and fresh land has been initiated since 1950. According to FAO's report India has largest area under plantation in the world as out of the total of world plantation area of 30.66 mha reported by 90 countries in 1990, India alone contained 13.23 mha under plantation, thus, claiming 43 per cent of the world's plantation area. Further, 5.571 mha of public lands were afforested between 1990-91 and 1995-96 (Anil Agrawal, et, al, 1999).

25.4 URBANIZATIN AND ENVIRONMENTAL POLLUTION

Increasing concentration of population in urban centres and origin and expansion of new urban centres consequent upon industrial expansion and development and employment potential are responsible for rapid rate of exploitation of natural resources in transformed forms and several types of environmental problems. The accumulation of wealth and availability of more economic and job opportunities have resulted into the concentration of population in the congested metropolitan cities and thus the formation and growth of slum areas in India. The urban population of India registered an overall increase of 15 percent from 1901 (25.8 million which was 10.84 per cent of the total India's population of 238.39 million in 1901) to 1991 (217.61 million, which is 25.71 per cent of the total country's population of 846.30 million in 1991, table 25.1). The density of urban population of India (1981) is 3000 persons per square kilometer against the density of rural population of only 160 persons. The urban population is estimated to become 33.68 per cent of country's total population (1263.54 million) in 2016 A.D. (table 25.2).

In fact, increasing urbanization means phenomenal increase in the concentration of human population in limited space which results in the increase of buildings, roads and streets, sewage and storm drains, pucca surface area, vehicle population (tables 25.3, 25.4), number of factories, urban wastes, aerosols, smokes and dusts, sewage etc. which cause several environmental problems mainly air and water pollution and garbage hazard. The phenomenal increase in the number of automobiles in the major cities of India viz. Bangalore, Kolkata, Chennai, Delhi, Hyderabad, Mumbai etc. from 1982 to 1996 (table 25.4) has caused serious **air pollution** (section 25.7) while increase in settlements and population has resulted in serious **water pollution** due to discharge of sewage coming out of domestic uses of water in house holds into the rivers. Air and water pollution in major cities will be discussed in the succeeding sections. See sections 25.6 and 25.7 for impact of urbanization on water and air pollution in India.

25.5 INDUSTRIAL DEVELOPMENT AND ENVIRONMENTAL POLLUTION

The mode of environmental degradation and pollution due to industrial expansion and development has been discussed in chapter 20 of this book. The rapid rate of industrial development in India has on one hand made the country to become self reliant in industrial produce and has enabled the country to earn foreign exchange through export of manufactured goods, it has also created hazardous environmental problems by polluting air, land and water not only in the urban and industrial centres but also in the rural areas on the other hand. Contamination of river water in Delhi (Yamuna), Kanpur (Ganga), Jetpur (Bhadar river, Gujarat), Patencheru (Chinnavagu, Peddavagu and Nakkavagu rivers in Medak district of Andhra Pradesh) etc. are a few examples of adverse effects of industrial effluents on India's aquatic environment. Similarly, emissions of nitrogen oxides and carbon monoxides from automobiles, of sulphur dioxide, carbon dioxides, carbon monoxides etc. from the factories have polluted air in the urban and industrial centres (e.g. Delhi, Kanpur, Kolkata, Mumbai etc.). Substantial land area has been degraded due to dumping of industrial wastes.

Chemicals, electricity, mining, non-metallic minerals, transport equipment related industries have registered rapid growth between 1984-85 and 1993-94. In fact, 17 categories of most polluting industries etc. have been identified by the Central Pollution Board (CPB) which pollute air and water through the emissions of gaseous and particulate pollutants and discharge of effluents. Out of these most polluting industries 77 per cent pollute water, 15 per cent pollute air, and 8 per cent pollute both air and water (Down to earth, March 15, 1998).

Table 25.10 : 10 most polluted areas of India

Area	CEPI Scores
1. Ankleshwar (Gujarat)	88.50
2. Vapi (Gujarat)	88.09
3. Ghaziabad (Uttar Pradesh)	87.37
4. Chandra Pur (Maharashtra)	83.88
5. Korba (Chhattisgarh)	83.00
6. Bhiwadi (Rajasthan)	82.91
7. Angul (Orissa)	82.09
8. Vellore (Tamil Nadu)	81.79
9. Singrauli (Madhya Pradesh)	81.73
10. Ludhiana (Punjab)	81.66

CEPI = comprehensive environmental pollution index

Basis = CEPI scores were derived on the basis of the following constituents of effluents (value in mg/l of land surface water).

TSS = total suspended solids, TDS = total dissolved solids

BOD = biochemical oxygen demand, COD = chemical oxygen demand

O and G = oil and gas, $NH_3 - N$ = ammonical nitrogen

CN = cynide, As = arcenic, Hg = mercury

Source : Down to Earth, July (1-15), 2011.

Table 25.11 : Top ten polluting industries

Industry	Number
1. Sugar	391
2. Basic drugs and pharmaceuticals	252
3. Distillery	177
4. Cement	116
5. Fertilizer	110
6. Thermal power plants	97
7 Pulp and paper	96
8. Pesticides	71
9. Leather	70
10. Dyes and dye intermediate	64

***Source** : Down to Earth, March, 15, 1998.*

Table 25.12 : Top ten polluting states

States	Number of Industrial units
1. Maharashtra	335
2. Uttar Pradesh	224
3. Gujarat	177
4. Andhra Pradesh	173
5. Tamil Nadu	119
6. Karnataka	85
7. Madhya Pradesh	78
8. Bihar	62
9. West Bengal	58
10. Rajasthan	49

***Source** : Down to Earth, March 15, 1998.*

It may be mentioned that maximum amount of pollutants comes from sugar, chemical and pharmaceutical industries. Dyeing and printing industries also pollute surface and groundwater whereas thermal power plants pollute air.

Industrial growth has made many of the Indian cities and towns as centres of health hazard due to pollution of groundwater, garbage hazard, river water pollution and air pollution. Ludhiana (Punjab), Jetpur (Gujarat), Tiruppur (Tamil Nadu) etc. are a few examples of industrial towns which tell the sad tale of severe environmental pollution due to industrialization and consequent urban growth. **Ludhiana** contributes about 50 per cent pollution load of the Sutlej river.

Jetpur (Gujarat) is another victim of severe pollution hazard caused by industrial development. The 1200 odd sari dyeing, and printing factories located at Jetpur on the Bhadar river in Rajkot district of Gujarat and 500 allied industrial units continued to spill chemicals and dyes into the Bhadar till 1998 and the resultant water pollution so adversely affected (ground water became red) 80,000 people mostly farmers and mill workers in Dhoraji region, downstream of Jetpur, that the judicial court had to order to install treatment plants by September 1998 and to pay a fine of Rs. 1.25 crore. The 90 km long stretch of the Bhadar river was so greatly polluted (1998) that it became unuseful even for irrigation.

The pollution of the Noyyal river in Tamil Nadu due to toxic effluents discharged from 800 odd dyeing and bleaching units located in **Tirruppur** is another sad story of industrial pollution. See sections 25.6 and 25.7 for impact of industrialization on water and air pollution in India.

25.6 : WATER POLLUTION IN INDIA

Water pollution implies pollution of surface water including river water, lake water, tank and pond water, groundwater and sea water through urbanization, industrialization, water withdrawal, agricultural runoff and religious and social functions. Here greater emphasis is given to the pollution of river water in India. The following terms should be understood before discussing various aspects of water pollution.

(A) Classification of water quality

Class A :	suitable for drinking purpose for human being without conventional water treatment but after disinfection.
Class B :	suitable for outdoor bathing for human being.
Class C :	drinking water source but after conventional treatment and disinfection.
Class D :	suitable for wildlife and fisheries.
Class E :	suitable for irrigation and industrial cooling.

(B) Criteria for determining water class

Criterion	Class A	Class B	Class C	Class D	Class E
1. DO (mg/l) minimum	6	5	4	4	—
2. BOD (mg/l) maximum	2	3	3	—	—
3. Total coliform count (MPN/100 ml)maximum	50	500	5000	—	—
4. pH	6.5-8.5	6.5-8.5	6.9	6.5-8.5	6.5-8.5

Explanation : DO : dissolved oxygen, BOD : biochemical oxygen demand and pH : measure of alkalinity or acidity of water-pH 7, neutral, less than pH7, acidic water, pH more than 7, alkaline water; MPN : most probable number.

Source : The Citizen's Fifth Report, Vol. II, 1999, CSE, New Delhi.

Grossly Polluted Rivers of India

Grossly polluted rivers are those in which there is vast variation in the required class and existing class of river water.

1. Sabarmati :	(i) between Ahmedabad city and Sabarmati Ashram, existing class E against desired class B. (ii) segment between Sabarmati Ashram and Vautha, existing class E against desired class D.
2. Yamuna :	(i) segment between Delhi and its confluence with Chambal, existing class partly D/E against desired class C. (ii) in the city limits of Delhi, Mathura and Agra, existing class partly D/E against desired class B.
3. Subarnarekha :	segment between Hathidam and Bahragara, existing class partly D/E against desired class C.
4. Godavari :	(i) segment between Nasik and Nanded, existing class partly D/E against desired class C. (ii) city limits of Nasik and Nanded, existing class partly D/E against desired class B.
5. Krishna :	segment between Karad and Sangli, existing class partly D/E against desired class C.
6. Damodar :	segment between Dhanbad and Haldia, existing class partly D/E against desired class C.
7. Gomti :	segment between Lucknow and its confluence with Ganga, existing class partly D/E against desired class C.
8. Kali :	segment between Modinagar and its confluence with the Ganga, existing class partly D/E against desired class C.
9. Kshipra :	(i) in the city limits of Ujjain, existing class E against desired class B. (ii) downstream of Ujjain, existing class E against desired class D.
10 Khan :	(i) in the city limits of Indore, existing class E against desired class B. (ii) downstream of Indore, existing class E against desired class D.
11. Hindon :	segment between Saharanpur and its confluence with the Yamuna, existing class E against desired class D.

Source : The Citizen's Fifth Report, Vol. I, 1999, CSE, New Delhi.

1. Yamuna River Pollution

The sacred Yamuna after taking its source from the Yamunotri in the Himalayas and covering a distance of 1376 km conflues with the Ganga at Allahabad to form the most sacred Prayag Sangam. Who knew that once the sister of Yamraj, the God of Death (Yama) as described in the epics would be made a man-killer by man himself in Kaliyuga. The Yamuna today is no longer the sacred Kalindi of 'Dwapar Yuga' but has now become a mere polluted sewage carrier. From the stand point of pollution level the entire course of the Yamuna from its source to its confluence with the Ganga is divided into 5 segments.

1. The Himalayan segment includes the 172 km long course of the river from its source to Tajewala barrage and is pollution free.

2. The upper segment includes 224 km long stretch of the river between Tajewala and Wazirabad. This segment receives enormous pollution load of agrochemicals (chemical fertilizers and pesticides) brought in by the surface runoff from the agricultural fields of Haryana state.

3. Delhi segment includes 22 km long stretch of the river between Wazirabad barrage and Okhla barrage. This segment is overloaded with enormous amount of pollutants discharged from numerous sewage drains of the city and hence the river has been polluted to such extent (partly D/E class) that it has become unusable even for human bath and animals.

4. Eutrophicated segment includes 490 km long stretch between Okhla barrage and its confluence with the Chambal. The load of micro-pollutants has become so high that BOD has become maximum. The residents of the cities of Agra and Mathura located in this segment have to pay the penalty of using highly polluted poisonous water, not created by them but the sin committed by Dehlites.

5. Diluted segment includes lower course of the river measuring 468 km between its confluence with the Chambal and Allahabad. The quality of water improves in this segment and becomes usable due to additional water discharged by the Chambal, the Betwa and the Ken rivers.

Upper segment between Tajewala and Wazirabad covers a distance of 224 km and has become the victim of rich agriculture of Haryana State. The farmers apply heavy doses of chemical fertilizers and pesticides to increase production. These agrochemicals are washed out by the runoff and are discharged into the Yamuna. Besides, wastes from Yamunanagar, Panipat, Sonepat, Karnal and other towns of Haryana are discharged into the river and these increase the pollution load with the result physico-chemical properties of the river water are changed to larger extent which adversely affect aquatic life. It may be mentioned that the intensity of pollution of the river is further increased due to withdrawal of water through two big canals (west and east Yamuna canals) resulting into substantial decrease in the volume of water except during a brief period of July-September.

Table 25.13 : Load of micro-pollutants in the Yamuna before it reaches Delhi (1995)

Micro-pollutants (pesticides) (in nanogram per litre of water)	July	March
T-BHC	218.83	11.11
Aldrin	not traceable	not traceable
T-Endosulphan	51.30	90.23
Dieldrin	30.44	20.42
T-DDT	203.44	7.55
Heavy metals (milligram per litre)		
Cadmium	0.01	0.01
Chromium	0.01	not traceable
Copper	not traceable	0.01
Iron	8.20	7.10
Nickel	0.02	0.05
Lead	not traceable	not traceable
Zinc	0.60	0.60

Source : Report on Water Quality Monitoring of the Yamuna, 1996, Central Pollution Control Board (CPCB), reported in Down to Earth, February 28, 1997.

Table 25. 14 : Pollution load entering the upper segment of the Yamuna, 1996

			Pollution Load		
Town	Wastes (MLD)	Suspended solids (kg/day)	Chemical oxygen demand load (COD, kg/day)	Biochemical oxygen demand (BOD, kg/day)	Cadmium (kg/day)
Karnal	36.67	6,634	5,548	2,843	<0.04
Panipat	21.63	10,970	10,784	3,493	0.10

Sonepat	27.70	9,212	6,496	1,746	0.30
Total	86.00	26,816	22,828	8,082	0.40

	Pollution Load					
Town	Chromium (kg/day)	Copper (kg/day)	Iron (kg/day)	Nickel (kg/day)	Lead (kg/day)	Zinc (kg/day)
Karnal	<0.04	2.6	180	10.0	<0.04	13.0
Panipat	<0.02	2.7	141	5.2	<0.02	8.2
Sonepat	11.00	4.0	168	15.0	3.30	16.0
Total	11.06	9.3	489	30.0	3.36	37.2

Source : The Citizen's Fifth Report, Vol I, 1999, CSE, New Delhi.

Delhi segment : Delhi metropolitan area is the biggest polluter of the Yamuna. The 22 km long segment between Wazirabad barrage and Okhla barrage is the most polluted segment of the Yamuna as 1,900 million litre of sewage from Delhi is discharged into the Yamuna per day whereas the total treatment capacity of treatment plants at Delhi is only 1,270 million litres per day. Thus, 630 MLD (million litre per day) sewage enters the Yamuna without treatment. Not only this, treatment plants release partly treated waste water into the Yamuna. It may be mentioned that the volume of water in the Yamuna becomes so low during winter and summer months because of closing of discharge from Wazirabad barrage that the flow of water becomes almost stagnant but the discharge of sewage into the river continues unabated resulting into phenomenal increase in pollution load of the river. Pollutant dilution requirement of the Yamuna is 75 per cent i.e. 75 litres of fresh water are required to absorb 100 litres of waste water but there is no supply of this additional fresh water. The waste of Delhi reaches the river through 19 major drains out of which 11 drains contribute, 2,800 MLD waste water which brings 200 tonnes of BOD and 160 tonnes of suspended solids per day in the river. Shahadra and Najafgarh drains discharge largest volume of sewage into the Yamuna (table 25.14). 'Before the Yamuna enters the capital, 100 milliliters of its water contain 7,500 disease causing bacteria but after receiving Delhi's share of sewage, carry 24 million bacteria according to pollution control experts'.

Table 25.15 : Major sewage drains and pollutants reaching Yamuna at Delhi.

Drain	Biological Oxygen Demand (BOD) (tonnes/day)	Suspended solids (tonnes/day)	Discharge (million litre per day, MLD)
1. Najafgarh	81.36	7.64	1667.84
2. Civil Mill	14.55	12.43	81.12
3. Power house	9.69	11.83	63.73
4. Sen Nursing Home	14.31	14.29	70.04
5. Baramullah	9.37	4.88	157.52
6. Shahadra	49.09	10.69	574.34

Source : Report on water quality monitoring of Yamuna, CPCB, 1996.

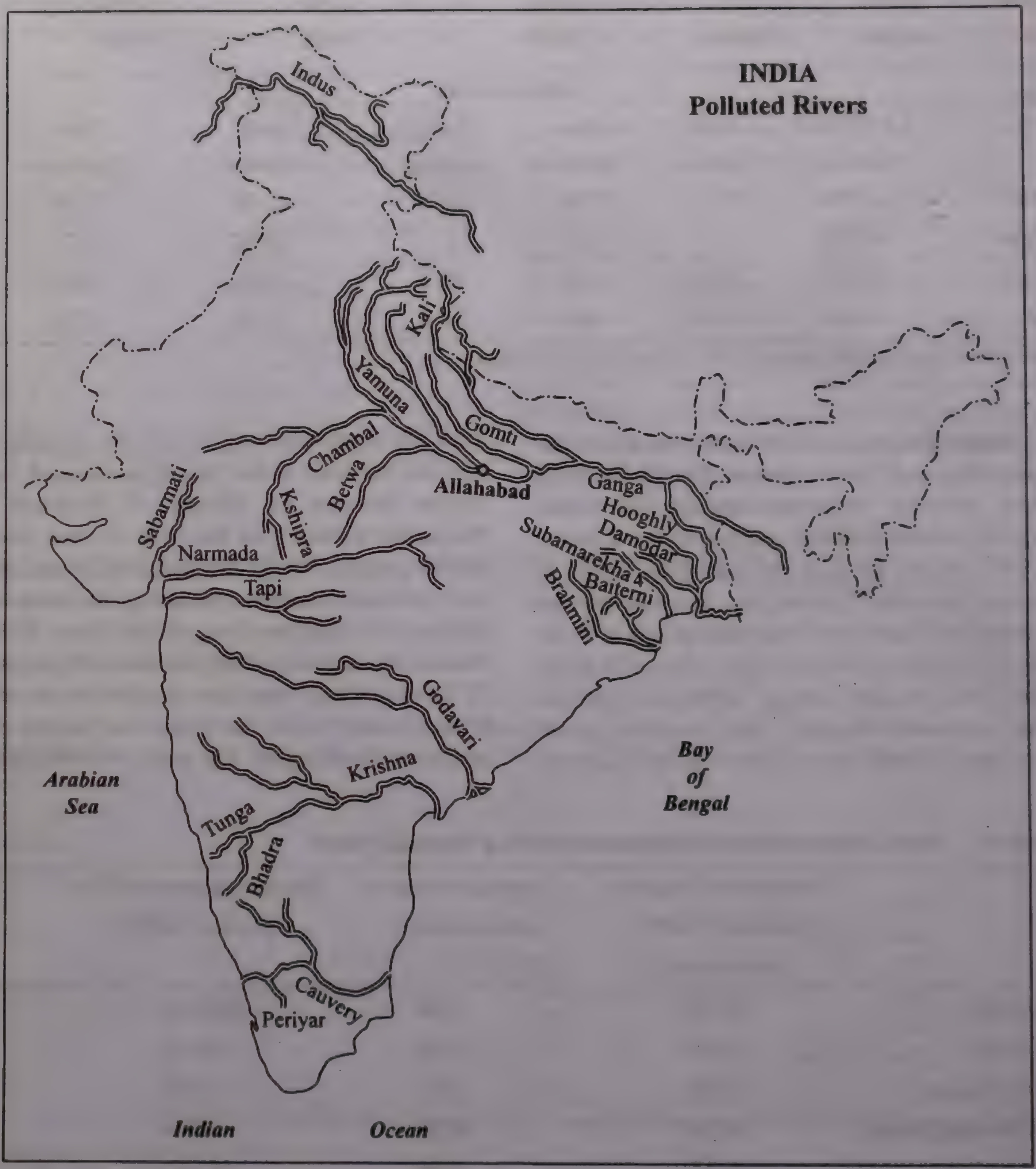

INDIA
Polluted Rivers
Indus
Kali
Yamuna
Gomti
Chambal
Betwa
Allahabad
Ganga
Hooghly
Damodar
Subarnarekha &
Baiterni
Brahmini
Sabarmati
Kshipra
Narmada
Tapi
Godavari
Krishna
Tunga
Bhadra
Cauvery
Periyar
Arabian Sea
Bay of Bengal
Indian Ocean

Fig. 25.1 : Heavily polluted rivers of India.

Eutrophicated segment is spread between Okhla barrage and the confluence of the Chambal with the Yamuna. The segment down stream of Delhi becomes more polluted because more waste water enters the river from Delhi, Agra and Mathura cities. The BHC load in the Yamuna in Delhi is

218.83 nanogram per litre whereas it increases to 1,733.23 nanogram per litre of water at Agra. Similarly, the DDT load of 203 milligram per litre of water at Delhi increases to 1,802.58 milligram per litre at Agra. The eutrophicated segment between Delhi and Agra becomes so heavily polluted through chemical pollutants that the water turns green, say becomes **green soup,** due to phenomenal growth of algae and phytoplanktons (eutrophicaton) in the river water. This is why this segment is called eutrophicated segment. The river water improves its quality downstream of Agra. The quality of water further improves downstream of the Yamuna-Chambal confluence.

Yamuna Action Plan (YAP) : Yamuna Action Plan (YAP) was launched in 1993 to study and control pollution in the Yamuna river. It may be noted that YAP is a part of ambitious Ganga Action Plan (GAP) Phase II which includes cleaning programme of three polluted tributaries of the Ganga viz. Yamuna, Gomti and Damodar. Initially, the YAP included pollution treatment programmes in 15 towns of Haryana (6), Uttar Pradesh (8) and Delhi but later on 6 more towns were added to the programme. The major programmes of the YAP are interception and diversion of waste water entering the river, installation of sewage treatment plants to clean the waste water entering the river through urban outfalls, setting up electric crematoria to burn human dead bodies, development of river banks and provision for low-cost sanitation schemes. There are total 127 schemes for the implementation of the above programmes of which shares of Uttar Pradesh, Haryana and Delhi are 48, 76 and 3 respectively. It may be mentioned that the YAP includes control of pollution only from urban and industrial sources and not from agricultural sources. It is significant to note that the cleaning programme of the Yamuna cannot be a success unless the withdrawal of substantial volume of water for irrigation purpose through major canals from the river by Haryana and Uttar Pradesh is minimised and sufficient fresh water is allowed in the river to maintain sufficient volume of water i.e. the states of Haryana and Uttar Pradesh ensure release of atleast 10 cumec (cubic metre per second) of fresh water into the river so that the quality of degraded river is improved.

2. Ganga River Pollution

The Ganga river, the most scared river of the Hindu community and known for its self-purification capacity since time immemorial, has now become tired due to relentlessly carrying everincreasing unwanted load of industrial and urban wastes contributed mostly by those people who consider their mother Ganga as door for heaven. Out of its total stretch of 2555 km from Gangotri to Gangasagar (Bay of Bengal) 600 km-long course of the river has been badly polluted.

Major pollutants of Ganga pollution include enormous quantities of sediments derived through accelerated rate of soil erosion in the source catchment areas of the Ganga due to deforestation and through rill and gully erosion in the reverine zones of the Ganga and its tributaries; sewer drains from urban areas located on the river banks; industrial effluents carrying waste waters, suspended and dissolved materials, toxic chemicals and metals etc. from various industries; garbages from cities; human and animal excreta from urban and rural settlements located along the river banks; burning of human dead bodies; corpses and dead animals; chemical fertilizers, pesticides, insecticides and herbicides (belonging to the category of synthetic chemicals) from agricultural fields; flowers, earthen lamp pots, earthen milk pots with diluted milk etc. by the people taken as offers during their worships; solid wastes mainly non-degradeable substances etc.

According to an estimate about 19,65,900 kilograms of polluted matters are discharged into the Ganga every year. Out of these pollutants the state of Uttar Pradesh contributes 10,90,000 kilograms while 3,70,000 kilograms of waste matters are contributed by the state of West Bengal (M. Lakshmi and P.C. Srivastava, Vijyan, January-March, 1986). The study undertaken by the Central Board for Preservation and Control of Water Pollution has revealed the fact that long stretches of the Ganga have become unsuitable for any beneficial human use near the cities of Kanpur and Varanasi; the water quality of the Ganga is on an average 'B' type (good water) upto Bithoor except near Kannauj where highly polluted sewer water from the city and polluted water brought down by the **Kali river** have degraded the river water beyond permissible limit; the quality of water further deteriorates to the category of 'D' and 'E' because of heavy influx of urban and industrial effluents into the Ganga; it becomes 'B' grade during November-March and 'C' grade during April-October at Allahabad; between Allahabad and the outskirts of Varanasi city the Ganga recovers its deficiency in terms of quality of its water but it becomes again highly polluted river at Varanasi because of enormous volume of urban effluents discharged into river water and thus water quality deteriorates to 'D' and 'E' grade.

Table 25.16 : Status of Ganga River Pollution (2005)

Locations	MPN (Coliform) bacteria PL=500/100ml	BOD PL=3g/l	DO PL=5g/l
Rishikesh	about 500	3.0	9.0
Haridwar		3.5	7.0
Kannauj	10,000,000	7-8	-
Kanpur			
Allahabad	>10,000	-	-
Varanasi	-	15-25	3.0
Patna	2,500	-	-
Kolkata	10,000	-	-

Source *: Report of Japanese Scientist (2005), BOD= biological oxygen demand, DO= dissolved oxygen. PL = permissible limit.*

It may be pointed out that the point pollution is responsible for most of the pollution of the Ganga because many sewage drains from riverine cities and industries drain into the river at specific points and thus pollute the water beyond permissible limit. Such point pollution is done by many big cities and industrial towns located on either bank of the river such as Kanpur, Allahabad, Varanansi, Patna, Barauni, Mokama, Kolkata (on Bhagirathi-Hoogli) etc. It is, therefore, desirable to discuss the pollution of the Ganga at specific locations.

(1) At Haridwar : Generally, the Ganga is considered to be least polluted between its source and Kannauj city but in fact the story of the Ganga pollution begins from Rishikesh, an important religious town upstream from Haridwar, where industrial wastes from 'Bharat Heavy Electricals Limited' (BHEL) have polluted the water. Besides, the oily liquids and toxic chemicals and other industrial wastes have increased the amount of carbon, sulphur and acids in the water to such an extent that the water is not only unsuitable for drinking and bathing purposes but it has also become unsuitable for irrigational purposes. The disposal of industrial wastes from the factory of Indian Drug Production Ltd. (IDPL) into river water also pollutes the Ganga. About 15 large and small sewage darins discharge urban wastes into the river at Haridwar. Community bathing, almost daily, discharges milk pots, bunches of flowers and leaves etc. into the river. Besides, 12-yearly **Kumbha Fair (Mela)** and 6-yearly **Aradha Kumbha Mela** attract large congregation of men and women from all over the country who come over here to take holy dip in the sacred mother Ganga. In the process, enormous quantities of pollutants are thrown by the pilgrims into the river during their worships.

(2) At Kanpur : The story of the Ganga becomes pathetic at Kanpur as enormous volume of urban sewage water, solid wastes and industrial toxic wastes are discharged into the river. It may be stated that about 200 million litres of waste water are discharged daily through sewers only (through 13 major 'nalas') into the Ganga at Kanpur. Besides, huge quantities of toxic effluents from numerous industrial units and thermal power plants are discharged daily into the river. The tanneries, large and small units numbering 151, of Kanpur city are heavily polluting the Ganga by discharging 5.8 MLD (million liters per day) of untreated effluents. Besides tanneries, industrial wastes from cotton and woollen textile mills, jute mills, synthetic rubber mills, paper and pulp mills, distilleries, sugar mills and factories manufacturing synthetic chemicals like D.D.T., pesticides etc. are discharged into the Ganga.

(3) At Allahabad : Allahabad represents the sacred confluence of the Ganga, the Yamuna and mythical Saraswati rivers. The major 'nalas' and drains discharge 78,000 litres of urban waste per minute or 112 million litres per day into the Ganga and the Yamuna and carry 32,164 kilograms of pollution load. Out of this pollution load 23,700 kilograms (about 70 percent of the total pollution load) are contributed by only four major 'nalas' (drains).

Besides urban effluents from Allahabad city, industrial wastes from Naini Industrial Complex are also discharged into the Yamuna river. The chemical fertilizer plant at Phulpur (about 40 km away from Allahabad) maintained by IFFCO releases about 55,000 cubic metres of polluted industrial wastes which are discharged into the Ganga through a nala per day. These toxic chemical pollutants pollute the Ganga upto a stretch of 16 kilometres.

'Teerthraj Prayag' (Allahabad) attracts largest human congregation in the world during 12-yearly **Kumbha Mela** (one of the most scared religious fairs of the Hindu community) at its confluence site. More than 30 million people converge at the sandy confluence of the Ganga and the Yamuna in a limited space and thus form the largest temporary megalopolis of the world. The peak population of around 30 millinon stays for 2 to 3 days but a minimum population of 5 million humans live in the temporary **Kumbha Nagar** (city) for about a month.

Immense quantities of human excreta, waste water and sullage coming out of human population of Kumbha Nagar are also discharged into the Ganga and thus water is so highly contaminated that it carries germs of cholera, typhoid, dysentry, diarrohea, jaundice and other diseases.

(4) At Varanasi : The Ganga water is heavily polluted at Varanasi through sewage waste water, burning of dead human bodies, worship offerings, community bathing and throwing of garbages etc. About 71 large and small sewer drains discharge about 15 MGD (million gallons per day) of effluents from the city into the Ganga. According to the survey conducted by B.D. Tripathi (B.H.U., Varanasi) about 23,000 to 32,000 dead bodies are burnt every year at different 'ghats' mainly Manikarnika and Harishchandra Ghats. About 11,000 to 15,000 tonnes of wood are burnt to burn these dead human bodies. Thus ashes of burnt woods, partially burnt woods, unburnt portions of dead bodies (weighing about 150 tonnes of flesh of partially burnt human dead bodies) and unburnt or partially burnt skeletons are thrown into the rivers which heavily pollute the water near several 'Ghats'. The study further reveals that out of total dead bodies burnt at two Ghats about 47 per cent are brought from out side Varanasi in the belief that if burnt at Varanasi the departed soul would go directly to the heaven. The wood required to burn dead bodies at Varanasi alone results in the deforestation of 15 to 115 hectares of forests each year. Besides, about 7000 dead animals are also thrown into the Ganga near Varanasi every year. The burning of dead bodies at Manikarnika and Harishchandra Ghats raises the water temperature between 30 to 50°C which reduces the dissolved oxygen by 30 to 50 per cent. This causes deaths of about 134 children every year.

(5) Bihar : About 250,000 gallons of sewage water are discharged into the Ganga from Patna city each day. The toxic effluents of Bata factory and McDowel Distellery at Mokama discharge 250,000 litres of toxic waste water into the Ganga every day. According to a study the fish cannot survive for more than 48 hours in the water at the site of outfall of the drains of Bata factory into the Ganga whereas fishes die within 5 hours at the site of outfall of drains of McDowel factory. The chemical wastes coming out of oil refineries at Barauni are discharged into the Ganga. There was fierce fire in the Ganga water upto a stretch of 2 kilometres at the outfall of industrial effluents in the Ganga. The fire continued for 16 hours and killed all of the aquatic organisms.

(6) At Kolkata : About 350 outfalls of urban and industrial effluents within a streth of 100 kilometres between Kalyani and Birlapur discharge enormous quantities of pollutants into Bhagirathi-Hoogli river. About 52 million gallons of waste water from domestic sources and more than 100 million gallons from industrial sources are discharged daily from Calcutta Metropolitan District into the Hoogli river. A 5-km stretch of the Hoogli between Bicholi Ghat and Garden Reach has become the worst polluted section. About 1500 human deaths were reported in Kolkata because of drinking of polluted water of the Hoogli during summer season. About 80 per cent of the inhabitants of

Kolkata always complain stomach trouble. People suffer from damage of kidney, skin diseases, polio, typhoid, jaundice etc. due to drinking of polluted water.

Ganga Action Plan (GAP)

The Ganga Action Plan Phase I was started in the year 1985 and Phase II was initiated in 1995. Out of its total stretch of 2,555 km from Gangotri to Gangasagar 600 km long course has been badly polluted. In all, 27 class I, and 73 class II and III towns, located on the banks of the Ganga, derive their water requirement from it. Thus, about one third of the urban population of India lives in the reparian tracts of the Ganga. The stretch between Allahabad and Farrakka having fairly larger mean annual flow of 7,626 m^3/s (s = second) is comparatively less polluted because of comparatively large volume of water whereas the pollution is not effectively diluted upstream of Allahabad (mean annual flow of 1,700 m^3/s and downstream of Farrakka (1,300 m^3/s) because of less volume of water.

In order to clean the Ganga and to keep the pollution to permissible level Ganga Action Plan Phase I in 1985 with main task of interception, and treatment of 873 million litres of waste water per day from 25 cities and diversion of treated water with the approved cost of Rs. 462.04 crore within a specified period of 6 years, was started but later on the target was extended upto March, 1997 for its completion. Table 25.17 depicts targetted treatment plan of the Ganga Action Phase I.

Table 25.17 : Target for interception and treatment of waste water (million litres per day)

State/City	Total waste water from class I towns (1985 basis)	Quantity to be intercepted (1985 basis)	Quantity to be treated (revised in 1995)
Uttarakhand			
Haridwar-Rishikesh	33.3	33.30	24.33
Uttar Pradesh			
Farrukhabad-Fatehgarh	9.3	2.70	3.96
Kanpur	360.0	160.00	175.50
Allahabad	110.0	90.00	60.00
Mirzapur	20.0	20.00	14.00
Varranasi	147.0	125.00	101.80
Total	679.6	431.00	379.59
Bihar			
Chapra	8.0	6.50	2.00
Patna	100.0	87.00	109.00
Munger	16.0	13.50	13.50
Bhagalpur	8.7	8.00	11.00
Total	132.7	115.00	135.50
West Bengal			
Beharampore	4.0	4.00	4.00
Nabadwip	4.0	4.00	4.00
North Howrah and Bally	12.0	12.00	30.00
Chandannagar	11.0	11.00	22.70

Serampore	20.0	20.00	18.90
Rest of East Bank	146.5		
(a) Titagarh		24.00	23.00
(b) Bhatpara		29.00	33.00
(c) Panihati		7.00	12.00
(d) Baranagar and Kamarhathi	7,00	19.00	40.00
(e) Kalyani		17.00	17.00
Howrah	75.00	75.00	45.00
Calcutta Metropolitan Area	255.00	105.00	122.00
Total	527.5	327.0	371.00
Ground Total	1339.8	873.00	886.69

Source : The Citizen's Fifth Report, Vol. I, 1999, CSE, New Delhi, based on Anon, 1997.

Table 25.18 : Summer average value of water quality of the Ganga under GAP

Station	Distance in kilometre from Rishikesh	Dissolved oxygen demand (mg/1) (acceptable limit 5 mg/1 or more for class B water)				
		1986	1990	1994	1995	1996
Rishikesh	0	8.1	8.1	9.6	9.0	8.9
Haridwar d/s	30	8.1	6.9	8.8	8.4	8.4
Kannauj u/s	430	7.2	7.1	8.8	8.0	8.0
Kannauj d/s	433	NA	6.1	7.2	7.8	7.9
Kanpur u/s	530	7.2	7.9	7.0	8.0	7.8
Kanpur d/s	548	6.7	4.4	4.6	6.8	6.4
Allahabad u/s	733	6.4	8.0	8.2	8.2	8.9
Allahabad d/s	743	6.6	6.9	7.4	8.2	8.5
Varanasi u/s	908	5.6	7.8	7.2	8.5	8.0
Varanasi d/s	916	5.9	7.2	6.8	8.0	7.7
Patna μ/s	1,188	8.4	7.7	7.0	6.8	7.3
Patna d/s	1,198	8.1	7.5	7.2	6.9	7.0
Ulberia	2,500	NA	6.4	6.8	6.6	5.5

Note : Summer average value for the months of March to June when temperatures are high and flow is low.

Source : The Citizen's Fifth Report Vol. I, 1999, CSE, New Delhi, based on Anon, 1997.

Table 25.19 : Summer average value for water quality of the Ganga under Ganga Action Plan

Station	Distance in kilometer from Rishikesh	Biochemical oxygen demand (BOD) (mg/1), acceptable limit less than 3 mg/1 required for class B whater				
		1986	1990	1994	1995	1996
Rishikesh	0	1.7	1.5	2.0	1.5	1.0
Haridwar d/s	30	1.8	1.8	2.1	1.7	1.1
Kannauj u/s	430	5.5	2.6	2.7	2.4	2.9

Kannauj d/s	433	NA	3.0	3.0	3.2	3.2
Kanpur u/s	530	7.2	2.7	5.0	2.0	2.8
Kanpur d/s	548	8.6	3.5	8.5	5.5	4.1
Allahabad u/s	733	11.4	2.6	2.3	4.5	2.5
Allahabad d/s	743	15.5	2.2	3.6	3.2	3.3
Varanasi u/s	908	10.1	2.1	1.8	2.6	2.2
Varanasi d/s	916	10.6	5.9	2.9	1.4	2.3
Patna u/s	1,188	2.0	0.3	1.6	1.5	2.0
Patna d/s	1,198	2.2	0.3	1.6	1.4	1.6
Ulberia	2,500	NA	1.0	3.2	2.8	2.0

Note : Mean value for the months of March to June when temperatures are high and flows are low. u/s = upstream, mg/1= milligram per litre.

d/s = downstream

Source : The Citizen's Fifth Report, Vol. 1999, CSE, New Delhi, based on Anon 1997.

Table 25.20 : Progress of Ganga Action Plan (Phase I) upto January 1997

State	Number of sanctioned scheme	Number of completed scheme	Number of ongoing scheme
1. Uttar Pradesh	106	104	2
2. Bihar	45	41	4
3. West Bengal	110	103	7
Total	261	248	13

Source : The Citizen's Fifth Report, Vol. I, 1999, CSE, Delhi, based on Anon 1997.

Ganga Action Plan Phase II (GAP Phase II) : Ganga Action Plan Phase I could not be as much successful as desired. Thus, GAP Phase II was launched in July, 1995 with the target of completing the incomplete schemes of GAP I and including additional towns for cleaning the polluted water. GAP II includes 29 towns of Uttar Pradesh (10), Bihar (11) and West Bengal (8) with a sanctioned cost of Rs. 416.33 crore. Besides, GAP II also includes the projects of cleaning of 3 additional tributaries of the Ganga viz. the Yamuna, the Gomti and the Damodar. The projects included under GAP II were expected to be completed by March, 1999 but the targets could not be achieved. Inspite of huge expenditure of billions of rupees on Ganga Action Plans for cleaning the river, the Ganga stands more polluted at Kanpur, Allahabad and Varanasi mainly during lean flow period. Every year the saints protest agaisnt the highly polluted water of the Ganga during annual bathing festival on 'Mauni Amavasya' (during the month of January) at Allahabad but no concrete actions are taken to atleast relese additional water into the Ganga to dilute the polluted water.

3. Damodar River Pollution

Damodar, once considered as **Sarrow of Bengal** for its notorious character and severe floods, has now become sorrow of both Bengal and Jharkhand due to its polluted water beyond imagination. The river takes its source over Khamar Pat in Palamau district and runs for a stretch of 563 kilometers upto its confluence with the Hoogly river. As regards its notorious character in terms of frequent floods, the Damodar and its two major tributaries (Barakar and Konar) have been tamed through a series of dams and reservoirs under

Damodar Valley Corporation (DVC) but the discharge of enormous quantity of pollutants coming out of the mines, industries and agricultural runoff has polluted and degraded the Damodar to such an extent that it has now become **biological desert** between Girdih and Durgapur having a stretch of 300 km, as no biological propagation is possible in the river. 'Today, many stretches of the Damodar and its tributaries resemble large drains carrying black, highly turbid water. The total suspended solids (TSS) count at most places along the upper and middle stretches of the river is 40-50 times higher than permissible limit' (Anil Agrawal, et. al, 1999). Pollutants comprising mine rejects mainly from coal mining and coal washeries, minerals, toxic effluents, chemicals, oil and grease are discharged untreated from about 50 large-scale and 100 medium and small scale industries located in the vicinity of the Damodar into the river. The pollution load from the industries comprises huge quantity of flyash,

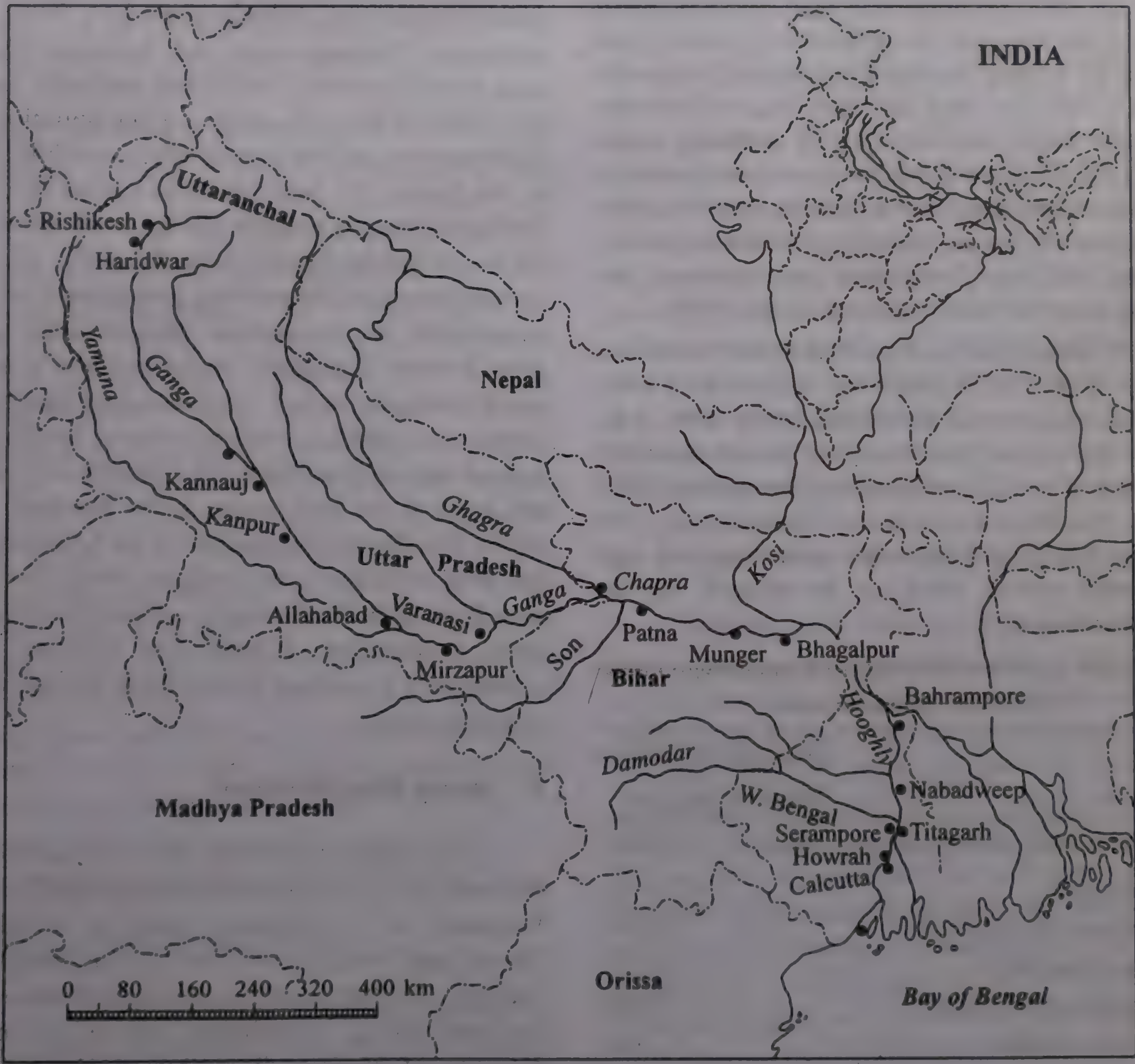

INDIA
Uttaranchal
Rishikesh
Haridwar
Yamuna
Ganga
Nepal
Kannauj
Kanpur
Ghagra
Uttar Pradesh
Chapra
Kosi
Allahabad
Varanasi
Ganga
Patna
Munger
Bhagalpur
Mirzapur
Son
Bihar
Bahrampore
Hooghly
Damodar
Nabadweep
W. Bengal
Serampore
Titagarh
Howrah
Calcutta
Madhya Pradesh
Orissa
Bay of Bengal
0 80 160 240 320 400 km

Fig. 25.2 : Location of point pollution of the Ganga River, Source : The Citizen's Fifth Report, Part I, CSE, New Delhi, page 93.

coal dust and waste over-burden materials, chromates, cynides, ammonia, phenols, alkali, tar and tar products, oil and grease. Average discharge of waste effluents from industrial units exceeds 50,000 million kilolitres per day (kl/d, table 25.27) resulting into, at a minimum estimate, 60 tonnes of BOD load, 2 tonnes non-metallic toxins and 1.2 tonnes of toxic metallic substances per day. Fifteen coal washeries in the region account for most of total suspended solids, oil and grease through direct slurry. The level of oil and grease is more than 2 mg/1 which is 200 times higher than permissible level for human use. The water of the Damodar is so heavily pollutted that it is not suitable even for agricultural purposes and cannot be treated through conventional treatment devices. 'Experts feel the only way to save the Damodar valley from these highly polluting industries (table 25.21) is to make massive investments in clean-up technologies or to switch over to a new generation of cleaner technologies. Industries exploiting the area's resources are, however, not willing to do so' (Anil Agrawal, et. al, 1999).

Damodar Action Plan (DAP) with total cost outlay of Rs. 24.54 crore was launched in 1996 and was expected to be completed by 2001 A.D. Under the action plan treatment plants would be installed to treat domestic and urban sewage of 12 towns (8 in Jharkhand and 4 in West Bengal). The sullage discharged from the industries and coal washeries would have to be treated by the concerned owners.

Table 25.21 : Effluent discharge by some major industries into Damodar river

Unit	Quantity in million kilolitres per day
1. ISSCO cold rolling mill and coke oven plant	29,523
2. Durgapur Project Ltd.	14,000
3. Hindustan Steel	4,730
4. Phillip Carbon Black	1,600
5. Carrew and Co.	150
6. Jamadaba Washery	18
7. Chandrapura Thermal Plant	11
8. Indian Explosive Ltd.	4

***Source :** The Citizen's Fifth Report, Vol. I, 1999, CSE, New Delhi, based on Arun Jhingran, 1990.*

4. Subarnarekha River Pollution

The Subarnarekha with a total stretch of 450 km long course drains over an area of 1.9 million hectares of the states of Jharkhand, West Bengal and Orissa. The river flows through mineral rich industrial belt of these states giving propsperity to the nation but has been heavily polluted due to accelerated soil erosion consequent upon rapid rate of deforestation, mineral extraction, industrial development and urbanization. Rapid rate of industrialization has resulted into the emergence of four big industrial belts viz. Ranchi-Hatia area, Muri area, Adityapur-Tatanagar area and Jadugoda-Ghatsila area which contribute maximum pollution load of the Subarnarekha. The daily organic pollution load from the rural and urban areas amounts to 264 tonnes in the basin. The rural and urban areas discharge biological oxygen demand (BOD) of 61 tonnes and 56 tonnes per day respectively. Recently, mining of radioactive materials and their processing have been responsible for radioactive contamination of the river between Judugoda (where uranium is mined) and Baharagora. In fact, 'unplanned and unregulated mining alongwith mineral processing industry, has caused serious environmental degradation in different parts of the river basin' (Anil Agrawal, et al, 1999). The cleaning programme of the Subharnarekha has been included in the National River Conservation Plan (NRCP). Domestic effluents discharged from Jamshedpur, Ranchi and Ghatsila urban centres will be treated before these are allowed to enter the river.

5. Betwa River Pollution

The Betwa river has been included in the National River Conservation Plan (NRCP) for the treatment of its polluted water in Mandideep, Bhopal and Vidisha where the river has been heavily polluted. The Betwa, after covering a distance of 573 km and having a catchment area of 4.9 million hectares of Madhya Pradesh and Uttar Pradesh enters the Yamuna river at Ghatampur near Hamirpur. The river is polluted in its upper reaches mainly from industrial and urban sources of Mandideep, Bhopal and Vidisha. The effluents from automobile workshops, electroplating units, distilleries, edible oil plants, fertilizer factories, ferrous and non-ferrous industries and hospitals, households etc. unload pollution load of various sorts into the Betwa via drains, lakes and tributary streams. The industrial and urban sources contribute BOD load of 37,000 kg and 220 kg daily respectively.

6. Periyar River Pollution

The Periyar river, once known for its medicinal miracle mainly for curing skin diseases but now tired up due to carrying enormous pollution load, emerges from the height of 2,400 m in the Western Ghats and drains over an area of 5,28,000 hectares housing 5 million people of Kerala. The river is one of the most dammed rivers of the world as it has been regulated at 12 sites by constructing dams and reservoirs but the river has now been extremely degraded and polluted due to indiscriminate human activities. An estimated 67,400 litres of waste water reach the river daily. The effluents discharged into the river contain highly toxic rare-earth chloride, rare-earth oxide, formic acid, copper sulphate, aluminium ingots, ammonium sulphate and sulphuric acid coming from 50 large and medium industries, and 2,500 small-scale industries on the banks of the river (Anil Agrawal, et,. al. 1999). Unregulated sand mining, at the rate of 43,700 tonnes a day, is a major factor in degrading the Periyar. Pesticides from the agricultural runoff are another source of river water pollution of the Periyar (annual use of pesticides and herbicides amounts to 150 tonnes). Though the river has not been included in the National River Conservation Plan (NRCP) but Periyar Action Plan with a cost outlay of Rs. 213 crore has been prepared (1997) to clean the river.

7. NOYYAL RIVER POLLUTION

A 173 km long seasonal river Noyyal has now been termed as a **dead river** because of heavy chemical pollution from 800 odd dyeing and bleaching units of Tirruppur industrial area located along the lower reaches of the river in Tamil Nadu. The river emerges from the Western Ghats in Kerala and drains into the Cauvery in Tamil Nadu. "The river may be minute in size as compared to other Indian rivers, but it has all the ingredients of a rivetting contest between use and abuse; between desperate and sustainable development. The issues that confront the river basin are limited water availability, multiple users, severe industrial pollution, confrontation and legal action' (Anil Agarawal, et. al, 1999). The water of the Noyyal has been so heavily chemically polluted downstream of Tirruppur, which houses 800 odd dyeing and bleaching units that the water is not usable even for agricultural purposes. This led to legal battle between the farmers and owners of textile processing industry and the judiciary came to the rescue of the river and the farmers by passing an historic judgment in relation to a public interest petition against industrial pollution filed in 1996 wherein the court directed the owners of the industry to pay for the complete cleaning of the river including dam, its reservoir, the bed of the river and to set up common effluent treatment plant by Nov. 1998. It may be pointed out that the effluents carrying chemical pollutants coming out of the dyeing and bleaching industrial units of Tirruppur have not only polluted the river water but have also heavily polluted groundwater as these units use and discharge 90 million litres of water daily.

8. Bhawani River Pollution

The Bhawani river, one of the most polluted rivers, having a perennial flow regime and a stretch of 217 km and draining over Coimbatore and Erode districts of Tamil Nadu is the tributary of the Cauvery river. The water of the river is used for agriculture (90 per cent of river water), industry (5 per cent) and for domestic use (5 per cent) but discharge of effluents from the industry, using only 5 per cent of the total river water, has polluted 95 per cent of the river water. The pulp unit of South India Viscose (SIV) is the largest polluter of the river as it withdraws 50 million litres of water from the Bhawani daily, thus, claiming 56 per cent of the total withdrawal of water from the river by all the industrial sectors combined, and releases 41 million litres as effluents into the river daily. The Bhawani River Protection Joint Council, an NGO, is monitoring the pollution and control mechanism in the Bhawani basin.

9. Cauvery River Pollution

Having a 1770 km long course the Cauvery river emerges from the Western Ghats in Karnataka and after draining through the states of Tamil Nadu and Kerala involving total catchment area of 8.8 million hectares of these three states and housing 28 million people (1981 census) ultimately drains into the Bay of Bengal. The Cauvery is one of the most disputed (dispute of sharing of water in Karnataka and Tamil Nadu states) and one of the most regulated rivers of the country as it has been be beaded by three major dams and reservoirs, a large number of barrages and weirs and anicuts and thus about 95 per cent of its water resource is exploited for agricultural, domestic and industrial purposes. The main polluters are agricultural, industrial and urban sectors. A large amount of agrochemical (chemical fertilizers and pesticides) reach the river as agricultural runoff. Coffee plantations in the districts of Coorg, Hassan and Chickmagalur contriute large amounts of organic pollutants and these raise the BOD level of the river by contributing 4,730 tonnes of BOD load each year. The BOD level of the Cauvery water ranges between 2400 and 4000 mg/l (Anil Agrawal, et. al, 1999). The heavy pollution load of the Cauvery, besides agriculture including coffee plantation, is contributed by the effluents discharged from 61 industries in Karnataka and 1139 units in Tamil Nadu. The major polluting industries are paper and pulp, chemical, engineering, and tanneries. The total waste water discharged into the Cauvery amounts to 87,000 cubic metres daily which has raised the level of total dissolved solids (TDS) to 1450 mg/l which is much higher than the permissible level of 500 mg/l (Anil Agrawal, et. al, 1999).

10. Godavari River Pollution

After taking its source in Nasik of Maharashtra, the sacred Godavari river with a strech of 1465 km drains a catchment area of 31 million hectares falling in Maharashtra, Madhya Pradesh and Andhra Pradesh and ultimately drains into the Bay of Bengal. The major sources of pollution load of the Godavari are agricultural runoff, sewage from urban centres and efluents from industrial centres. The average annual rate of application of chemical fertilizers in the basin catchment is 49.34 kilograms per hectare and substantial amount of pesticides (21,586 tonnes per year) the major portion of which is washed out and reaches the river and its tributaries through agricultural runoff. Total BOD load of the river is 998 tonnes of which about 18 per cent is contributed by the industries. BOD concentration in the river water is more than 3 grams per litre of water.

11. Krishna River Pollution

The Krishna river, after rising on the flanks of the Mahabaleshwar plateau in Maharashtra, and taking a journey of 1337 km through the states of Maharashtra Karnataka and Andhra Pradesh and drainng an area of 26 million hectares, debouches in the Bay of Bengal. Total annual use of pesticides for crop protection amounts to 7,941 tonnes which are washed out by surface runoff and resultant agricultural runoff raises the concentration of chemical pollutants in the river (120 mg/l of nitroegen, 26 mg/l of phosphorous and 31 mg/l of potassium). The domestic sector contributes pollution load of 1.4 million kg per day of which rural and urban sectors share almost identical amount. The pollution load from industrial source comes from Pimpri, Chinchwada New Corporation (Pune, Maharashtra), Harihar Polyfibres Limited in Dharwar district (Karnataka), Mysore Paper Mills, Vishweswarya Iron and Steel Limited (Karnataka), industrial Complex at Rangareddy and distilleries in Vijayawada (Andhra Pradesh).

12. Bhadar River Pollution

The Bhadar river in Rajkot district of Gujarat has become the victim of chemical pollutants discharged from the 1200 odd sari dyeing and printing units located at Jetpur, a small industrial town with a population of 1,25,000 (1997) and 500 allied industrial units. These industrial units continued to spill chemicals and dyes directly into the Bhadar till 1998 and the water quality went down substantially. The level of suspended solids touched the figure of 500 mg/l against the permissible limit of 100 mg/l. The concentration of sodium reached 30 mg/l against the safe limit of 0.2 mg/l and sulphate crossed the permissble limit of 2 mg/l by registering the concentration of 43 mg/l. The 90 km long stretch of the Bhadar river has been so greatly polluted that it has become unuseful even for irrigating crops. The groundwater became red. The resultant water pollution so adversely affected 80,000 people mostly farmers and mill workers in Dhoraji region downstream of Jetpur that the judicial court has to order the mill owners to install treatment plants immediately (Sept. 8, 1998) and to pay a fine of Rs. 1.25 crore.

25.7 AIR POLLUTION IN INDIA

The air in the urban and industrial locations is being steadily polluted and the air pollution load is increasing with increase in the number of industrial units (tables 25.17, 25.18 and 25.19) and vehicles in the urban centres (table 25.3 and 25.4). The phenomenal increase in the number of vehicles in the country is the most significant polluting factor of urban air. The major air pollutants are sulphur dioxide (SO_2), nitrogen oxides (NO_x), suspended particulate matter (SPM), carbon monoxide (CO), benzene, lead, hydrocarbons etc.

Table 25.22 : National ambient air quality standard (annual average)

Pollutants	Indian air quality standard			WHO recommendations
	Sensitive areas	Residential rural and other areas	Industrial areas	
Sulphur dioxide (μg/cum)	15	60	80	40-60
Nitrogen oxide (μg/cum)	15	60	80	150 (24 hours average)
Ozone (μg/cum) (8 hours average)	-	-	-	100-200
Suspended Particulate matter (μg/cum)	70	140	360	60-90
Lead (μg/cum)	0.50	60	120	-
Carbon monoxide (μg/cum)	1.0	2.0	5.0	10

Note : μg = microgram, cum = cubic metre

***Source :** The Citizen's Fifth Report, Vol I, 1999, CSE, New Delhi.*

Sulphur Dioxide (SO_2)

Emission of sulphur dioxide (SO_2) is closely related to industrialization and phenomenal growth in urban automobiles as SO_2 is emitted mainly from the combustion of sulphur-rich fossil fuels e.g. coal and mineral oil. It is significant to note that SO_2 was found to be significant air pollutant upto 1980 but thereafter concentration of SO_2 slightly declined due to switch over from firewood, coal and kerosene as cooking fuel to liquefied petroleum gas (LPG). The eastern and western industrial belts recorded relatively higher level of SO_2 between 1990-95. Gajroula (in Western U.P.), Howrah, Ankleshwar, Baroda (Vadodra) and Surat recorded higher level of SO_2 than the national standard for residential areas (60 μg/cum). In most parts of the country annual average of SO_2 concentration remained well below national standards for SO_2.

Nitrogen Oxides (NO_x)

The five-year data (1990-95) of mean annual level of nitrogen oxides indicate sharp rise but the level remained well within national standards for NO_x (60 μg/cum, mean annual) except in Gajroula (Western Uttar Pradesh), Pondicherry, Howrah, Jabalpur, Alwar (Rajasthan) and Kota which recorded NO_x above national standards. Howrah recorded highest mean annual concentration of 204.35 µg/cum in 1995 whereas maximum annual concentration remained above 200 µg/cum since 1990. Though mean annual concentration of NO_x in the industrial belt of the western region of the country registered increase but remained below national standards e.g. industrial towns of Surat, Vapi, Rajkot, and Ankleshwar but Ahmedabad accounted for very high level of maximum annual value of 490 µg/cum in 1991. Similarly, the mean annual concentration of NO_x in Delhi though steadily increased but remained below national standards but the sudden spurt in the maximum levels from 47 µg/cum in 1991 to 324 µg/cum in 1995 is, in fact, a matter of serious concern. The introduction of CNG-operated buses and three wheelers and metro-rails in Delhi has now brought down the level of air pollution by almost all of the ingredients.

Suspended Particulate Matter (SPM)

The national standard for SPM concentration is 140 µg/cum in the residential area. It is a matter of concern that SPM has emerged as one of the most dangerous air pollutants and its concentration has substantially increased since 1990. The concentration of SPM has registered constant increase between 1990-95 when the SPM level was recorded 2 to 3 times higher than the national standard in the northern, western, eastern and southern regions but comparatively southern region remained less polluted. Most of the SPM recording stations in the northern region recorded more than 300 µg/cum of SPM during 1990-95. Delhi recorded maximum concentration of above 1000 µg/cum in 1987 whereas mean annual level remained well above 400 µg/cum during 1990-95. In the southern region, Hyderabad and Vishakhapatnam (Andhra Pradesh), Kottayam, Ernakulam and Thiruwanthpuram (Kerala), Mysore (Karnataka) and Pondicherry recorded higher level of SPM concentration than national standard between 1990-95. In the eastern region Kolkata and Howrah have reached critical SPM level as it consistently remained above 1000 µg/cum between 1987-95. Most of the cities in the western region including Ahmedabad, Baroda, Surat and Rajkot in Gujarat, Bhopal, Indore in Madhya Pradesh, Mumbai and Nagpur in Maharashtra, Alwar and Jaipur in Rajasthan recorded SPM concentration above national standard level between 1990-95.

Air Pollution in Metropolitan Cities

Metropolitan cities are heavily polluted but Chennai has comparatively cleaner air than other metropolitan cities. According to WHO's report Delhi ranked 4th most polluted city in the world in 1980-84 while Kolkata, Delhi and Mumbai ranked 5th, 7th and 15th among the most polluted cities in the world in 1990. Delhi's air is polluted through four sources viz. automobiles, thermal power plants, industries and households which contribute 64, 17, 12 and 7 per cent of air pollution. The number of automobiles in Delhi registered rapid increase between 1982 (0.593 million) and 1996 (2.63 million). It was estimated that the share of air pollution through automobiles would increase to 72 per cent beyond 2000 A.D. but the introduction of metro-rails in Delhi has reduced air pollution. Similarly, the introduction of CNG-operated buses and autorikshas has also contained air pollution in the capital city. Automobiles contribute 52 per cent of total air pollution load in Mumbai, industries and thermal power plants contribute 48 and 33 per cent of emissions of sulphur dioxide, and fumes coming out of huge dumps of garbage are also increasing and these are aggravating air pollution problem in Mumbai. Automobiles account for 30 per cent of air pollution load in Kolkata Metropolitan District. The major pollutants of Kolkata's air are suspended particulate matter (SPM) and carbon monoxide (CO). The concentration of SPM in Kolkata's air increased from 237 µg/cum in 1990 to 354 µg/cum in 1995, which far exceeded the national standards. The concentration of CO exceeded 10 times the permissible level of 2 µg/cum in 1996.

Table 25.23 : Estimated vehicular emission of pollutants in metropolitan cities of India, 1994

City	Vehicular emissions (tonnes per day)					
	PM	SO_2	NO_x	HC	CO	Total
Delhi	10.30	8.96	126.46	249.57	651.01	1046.30
Mumbai	5.59	4.03	70.82	108.21	469.92	659.57
Bangalore	2.62	1.76	26.22	78.51	195.36	304.47
Kolkata	3.25	3.65	54.69	43.88	188.24	293.71
Chennai	2.34	2.02	28.21	50.46	143.22	226.25

Source : Central Pollution Control Board (1995), PM = particulate matter, SO_2 = sulphur dioxide, NO_x = nitrogen oxides, HC = hydrocarbons, CO = carbon monoxide.

Monitoring of Air Pollution in India

The monitoring of ambient air quality in India was started by National Environmental Engineering Research Institute (NEERI) in 1978 but this programme was discontinued in 1989. This practice was started by the Central Pollution Control Board (CPCB) in 1985 as National Ambient Air Quality Monitoring (NAAQM) programme. The number of monitoring stations increased to 84 stations in 1987 and 290 (covering 92 cities and towns in 28 states) in 1995. The level (load) of concentration of SO_2, NO_x, SPM, RPM (PM_{10}), NH_3, CO is regularly measured on daily basis in major cities.

Urban Air Pollution Management

The Govt. of India has taken a number of measurs to mitigate the everincreasing problem of air pollution in India. Some of such mesures are given below :

- A few legislative measures have been adopted to protect the quality of environment including air quality such as (1) Air (prevention and control of pollution) Act 1981, (2) Environment (Protection) Act, 1986, (3) adoption of Male Declaration on Control and Prevention of Air Pollution and its Likely Transboundary Effects for South Asia (1998) etc.
- The Government has laid down ambient air quality standards for different categories of areas such as industrial, residential/rural/other, and sensitive areas for the concentration of certain air pollutants such as SO_2, NO_x, SPM, RPM (PM_{10}), NH_3 etc. for short-term (24 hourly) and long-term (yearly) periods. The concerned units and authorities have to follow the norms of air quality standards
- Norms have been fixed for the emission of maximum possible limits for various pollutants emitted from different categories of industries.
- Under the provision of 'environment audit' every polluting industrial unit has to submit 'environment statement' to the concerned State Pollution Control Board (SPCB). This is mandatory for polluting industries.
- It is mandatory for the industries to use pollution control technologies.
- Stringent emission norms have been fixed (1991, 1996 and 2000) for automobiles, such as Euro I (Bharat I), Euro II (Bharat II).
- Provision for cleaner fuel quality for the automobiles.
- Identification of pollution problem areas and implementation of action plans for the mitigation of air pollution problems under the supervision of Ministry of Forest and Environment (MEF).
- Monitoring of implementation of action plans by the Environment Polluton (Prevention and Control) Authority for the National Capital Region (NCR)

It may be concluded that inspite of several measures adopted for the control of air pollution mainly in urban areas, the serious problem of air pollution could not be mitigated upto satisfactory level. It is also true that certain measures such as introduciton of CNG-operated automobiles mainly buses and autorikshas, and metro-railways in Delhi has certainly contained air pollution.

Table 25.24 : Level of noise pollution in big cities of India (dB unit)

City	Industrial area		Commercial area		Residential area		Quiet area	
	day	night	day	night	day	night	day	night
Kolkata	78	77	82	75	79	65	79	65
Mumbai	76	65	75	66	70	62	66	52
Chennai	71	66	78	71	66	48	63	49
Bangalore	78	53	76	57	67	50	67	-
Acceptable level (according to Central Pollution Control Board)	75	70	65	55	55	45	50	40

Source : Down to Earth, August, 15, 1998.

25.8 : NOISE POLLUTION IN INDIA

Noise pollution (see, chapter 21 of this book) level in India is rising with industrial growth and urban expansion. Noise level in the commercial areas of almost all of the major Indian cities has far exceeded acceptable level of 65 dB during day time and 55 dB in the night. Noise level has become very high even in the quiet areas of the cities. Noise levels in different localities of Lucknow city are above 80 dB and have reached 100 dB in certain localities. Major sources of noise pollution in Indian cities are automobiles, busy market, loudspeakers, traffic etc. Every nook and corner of a city is echoed by blistering and deafening noise created by over-crowded loudspeakers turned at full volume during festivals of all communities, cultural programmes, public addresses, national festivals, Indian victories in games and sports in international encounters etc. Most of big cities of India have high level of noise pollution generally above 70 dB e.g. Delhi (89 dB), Kolkata (87 dB), Mumbai (85 dB), Chennai (89 dB), Cochi (80 dB), Madurai (75 dB), Nagpur (75 dB), Thiruwanthapuram (70 dB) etc.

26

DISASTER MANAGEMENT AND ENVIRONMENTAL LAWS IN INDIA

Different aspects of disaster reduction and management, namely meaning and classification of natural hazards and disaster, difference between hazards and disasters, strategies of disaster management etc. have already been discussed in chapter 17 of this book. In this chapter attempts have been made to discuss different aspects of disaster management in India and important legislations regarding various aspects of environment. This chapter includes the consideration of the following :

- major natural hazards and disasters in India,
- strategies of disaster reduction and management,
- institutional and policy framework of disaster management,
- management of major disasters, and
- major environmental laws.

India's Vulnerability to Natural Disasters

- Coastal states, particularly east coast and Gujarat are most vulnerable to **cyclone disaster.**
- About 40 million hectare land mass is vulnerable to **flood disaster.**
- About 68 per cent of net sown area is vulnerable to **drought disaster.**
- About 55 per cent of total geographical area of the country falls in seismic zones III-V and is vulnerable to **earthquake disaster.**
- Sub-Himalayan region and Western Ghats are vulnerable to **landslide disaster**.
- Coastal states (both eastern and western) are vulnerable to **tsunami disaster**.
- 199 districts of the country are vulnerable to **multi-natural hazards**.
- Out of 199 districts, 125 in 12 states of the country are most vulnerable to **multiple natural hazards.**

Occurences of Natural Disasters in India (number of incidents)

	1970-79	1980-89	1990-98
Floods	40	50	58
Earthquakes	04	11	03
Cyclones	19	21	17
High Winds	09	19	09

26.1 HIGH RISK MULTI-HAZARD ZONES

The major natural hazards and disasters which very often strike India include the following :

- earthquakes,
- cyclonic storms,
- tidal surges,
- floods,
- droughts,
- landslides, and
- tsunami (but it is very infrequent event).

The Govt. of India compiled a **national vulnerability atlas** in the year 1997 depicting hazards and disasters-prone areas. The Ministry of Home Affairs (MHA) and United Nations Development Programme (UNDP) have prepared a list of 125 districts in the country as the **'most hazard-prone areas'** of India which also include the four major metropolitan cities of Delhi, Mumbai, Kolkata and Chennai and capital cities of 8 states (fig. 26.1).

Earthquake-Prone Areas

India is adversely affected by moderate to severe earthquakes in different parts of the country mainly the Himalayan regions, north Bihar, N.E.

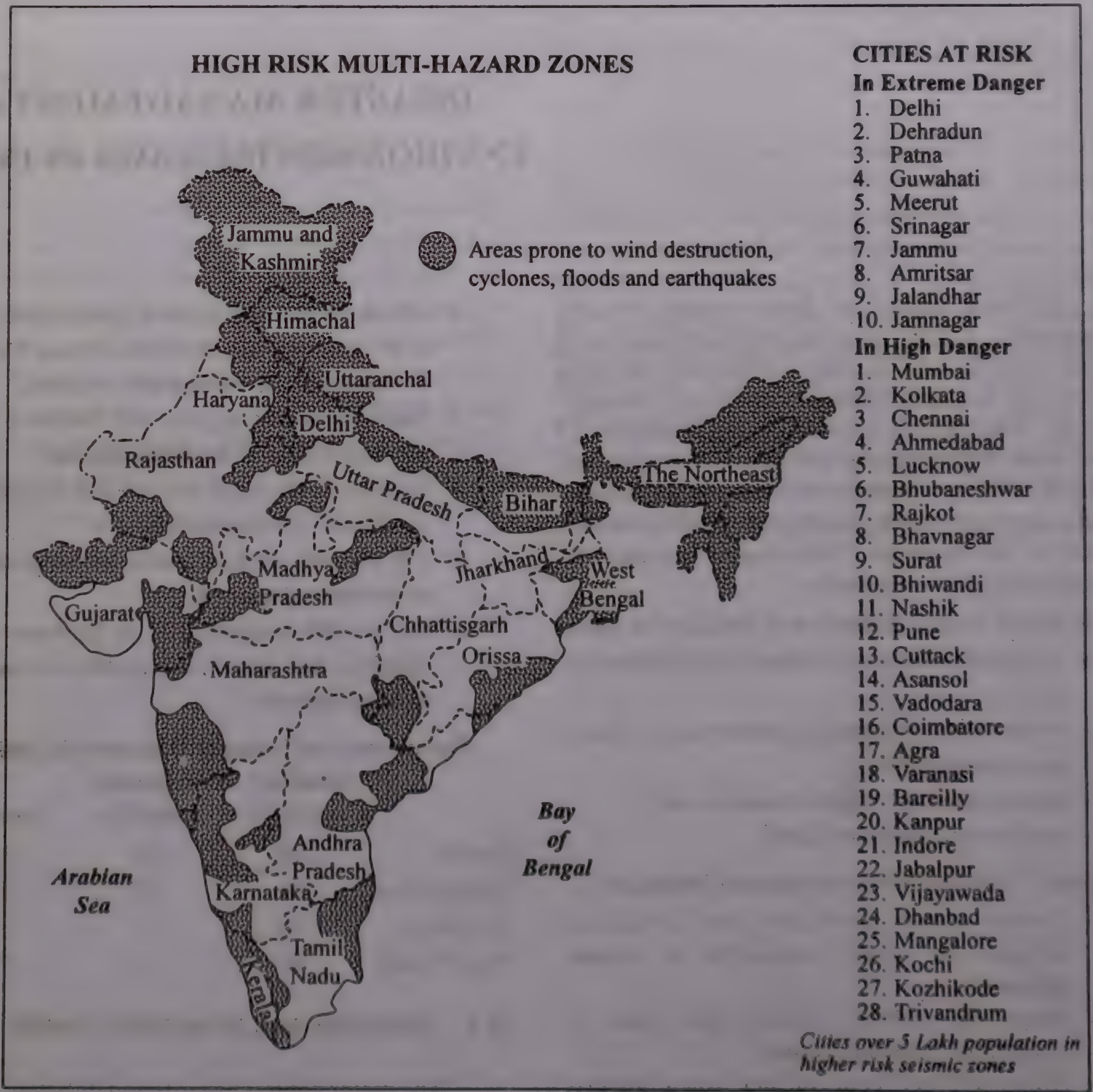

HIGH RISK MULTI-HAZARD ZONES
Areas prone to wind destruction, cyclones, floods and earthquakes
Jammu and Kashmir
Himachal
Uttaranchal
Haryana
Delhi
Rajasthan
Uttar Pradesh
Bihar
The Northeast
Gujarat
Madhya Pradesh
Jharkhand
West Bengal
Chhattisgarh
Orissa
Maharashtra
Andhra Pradesh
Karnataka
Tamil Nadu
Kerala
Arabian Sea
Bay of Bengal
CITIES AT RISK
In Extreme Danger
1. Delhi
2. Dehradun
3. Patna
4. Guwahati
5. Meerut
6. Srinagar
7. Jammu
8. Amritsar
9. Jalandhar
10. Jamnagar
In High Danger
1. Mumbai
2. Kolkata
3 Chennai
4. Ahmedabad
5. Lucknow
6. Bhubaneshwar
7. Rajkot
8. Bhavnagar
9. Surat
10. Bhiwandi
11. Nashik
12. Pune
13. Cuttack
14. Asansol
15. Vadodara
16. Coimbatore
17. Agra
18. Varanasi
19. Bareilly
20. Kanpur
21. Indore
22. Jabalpur
23. Vijayawada
24. Dhanbad
25. Mangalore
26. Kochi
27. Kozhikode
28. Trivandrum
Cities over 5 Lakh population in higher risk seismic zones

Fig. 26.1 : High risk multi-hazards zones of India, source : Rajesh Ramchandran, Outlook, 2005.

India, Gujarat, Maharashtra etc. After shocking earthquake of Koyna in 1967 in Maharashtra, India has been severely rocked in August, 1988 (Darbhanga quake, 6.7), October, 1991 (Utarkashi, Uttarakhand, 6.6), September, 1993 (Latur, Maharashtra, 6.3), May, 1967 (Jabalpur, M.P. 6.0), March, 1999 (Chamoli, Uttarakhand, 6.8), January , 2001 (Bhuj, Gujarat), October, 2005 (Jammu and Kashmir, epicenter being in Muzafferabad in Pok) etc. (see table 18.7 in chapter 18 of this book).

On the basis of magnitude of **damage risk** India has been divided into the following 5 **damage risk zones** (fig. 26.2) :

(1) Zone I of least damage risk includes the places of some parts of Punjab and Haryana, plain areas of Uttar Pradesh, portions of plains of north Bihar and West Bengal, delta areas of the Godavari, coastal plain areas of Maharashtra and Kerala, desert areas of Rajasthan and most areas of Gujarat except Kutch region.

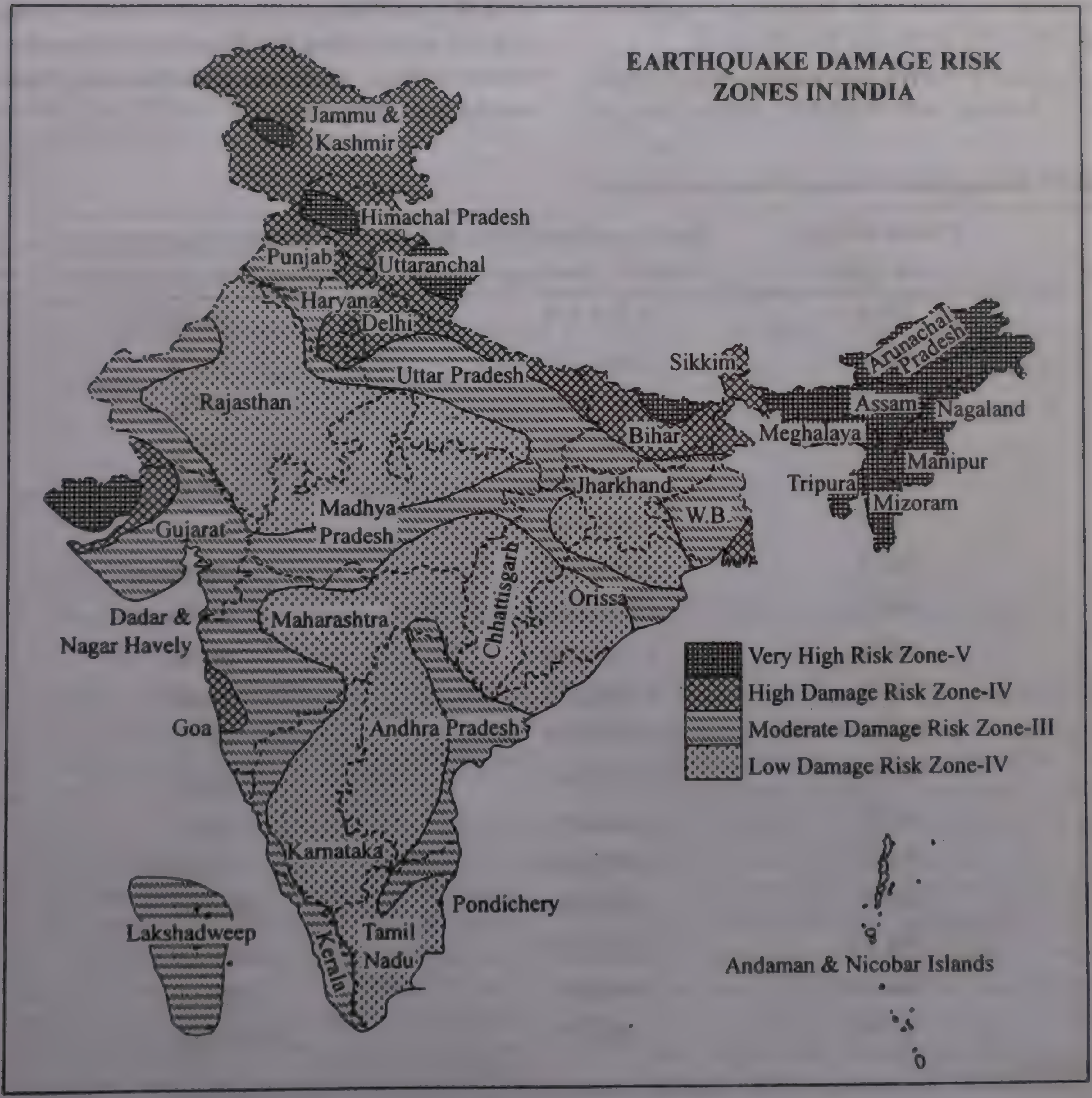

EARTHQUAKE DAMAGE RISK ZONES IN INDIA
Jammu & Kashmir
Himachal Pradesh
Punjab
Uttaranchal
Haryana
Delhi
Uttar Pradesh
Sikkim
Arunachal Pradesh
Assam
Nagaland
Meghalaya
Manipur
Tripura
Mizoram
Bihar
Rajasthan
Jharkhand
W.B.
Madhya Pradesh
Gujarat
Chhattisgarh
Orissa
Dadar & Nagar Havely
Maharashtra
Goa
Andhra Pradesh
Karnataka
Pondichery
Lakshadweep
Tamil Nadu
Kerala
Andaman & Nicobar Islands
Very High Risk Zone-V
High Damage Risk Zone-IV
Moderate Damage Risk Zone-III
Low Damage Risk Zone-IV

Fig. 26. 2 : Earthquake damage risk zones of India. Source : UNDP Website.

(2) Zone II of low damage risk includes southern Punjab and Haryana, southern parts of plains of Uttar Pradesh, eastern Rajasthan, coastal districts of Orissa and Tamil Nadu etc.

(3) Zone III of moderate damage risk represents the areas of southern and south-eastern Rajasthan, most of Madhya Pradesh, Maharashtra and Karnataka, southern Bihar, Northern and north-western Orissa etc.

(4) Zone IV of high damage risk covers Jammu and Kashmir, Himachal Pradesh, northern Punjab and Haryana, Delhi, western Uttar Pradesh, 'tarai' and 'Bhabar' ragions and Himalayan regions of Uttarakhand, and Bihar and Sikkim areas.

(5) Zone V of very high damage risk includes parts of Jammu and Kashmir, some parts of Himachal Pradesh, Uttarakhand, extreme north Bihar, entire north-eastern India and Kutch region of Gujarat.

Though the plains of West Bengal comes under the zone of least damage risk but the devastating severe earthquake of Kolkata of 11 October, 1737 killing 300,000 people put a question mark against this concept. The zone of very high damage risk of Kutch region of Gujarat registered most devastating killer earthquake on January 26, 2001 (8.1 on Richter scale) in its seismic history of past 182 years killing 50,000 to 100,000 people. The towns of Bhuj, Anjar and Bhachau were flattened and razed to the ground.

Table 26.1 : Damage due to natural disasters in India

Year	People affected (in lakh)	Houses and buildings, partially or totally, damaged (Number)	Amount of property damage/loss (Rs. Crores)
1985	595.6	2,449,878	40.06
1986	550.0	2,049,277	30.74
1987	483.4	2,919,380	20.57
1988	101.5	242,533	40.63
1989	30.1	782,340	20.41
1990	31.7	1,019,930	10.71
1991	342.7	1,190,109	10.90
1992	190.9	570,969	20.05
1993	262.4	1,529,916	50.80
1994	235.3	1,051,223	10.80
1995	543.5	2,088,355	40.73
1996	549.9	2,376,693	50.43
1997	443.8	1,103,549	NA
1998	521.7	1,563,405	0.73
1999	501.7	3,104,054	1020.97
2000	594.34	2,736,355	800.00
2001	786.19	846,876	120.00
2006* (only tsunami)	27.92	253,377	11,594.91

***Source :** Annual Report, Natural Disaster Management Division (NDMD; Ministry of Agriculture)*

**Ministry of Information and Broadcasting, Govt. of India, 2005.*

Cyclone-Prone Areas

The cyclonic storms originating in the Bay of Bengal and the Arabian Sea frequently strike the coastal districts (both eastern and western coasts) of India almost each year and cause huge damage to men and materials (table 26.2). The tropical cyclonic storms do the damage through very high velocity wind, incessant and high intensity rainfall and several meters high tidal surges. The quantum of damage by the cyclones is maximum in the coastal areas and gradually deceases in land due to dissipation of strorm energy. The following criteria for the classification of tropical cyclones (low pressure systems) as developed by the World Meteorological Organization (WMO) have been adopted by the Meteorological Department of India (IMD) :

Types (categories) of tropical Disturbances	Associated wind speed in circulation
1. Low pressure area	< 31 kmph
2. Depression	31-49 kmph
3. Deep depression	50-61 kmph
4. Cyclonic storm	62-88 kmph
5. Severe cyclonic storm	89-118 kmph
6. Very severe cyclonic storm	119-221 kmph
7. Super cyclonic storm	>120 kmph

kmph = kilometer per hour

Since tropical cyclonic storms originate and develop in certain favourable atmospheric and oceanic conditions and hence there are temporal, say seasonal variations in their behaviours in terms of their places of origin, tracks of their movement and attainment of their various stages of development and intensities. All these behavioural characteristics of tropical cyclones originating in the Bay of Bengal and the Arabian Sea make their prediction and warning easier.

Table 26.2 : Damage due to cyclonic disaster in Orissa in October, 1999

Date of occurrence	Total No of districts	Districts affected (No.)	Villages affected (No,)	Population affected (lakh)	Crop area affected (lakh ha)	Houses damaged (No.)	Human life loss (No.)	Cattle loss (NO.)
Oct. 17-18 1999	30	4	5,181	37.47	1.58	331,580	199	10,578
Oct. 29-30 1999	30	12	14,643	129.22	18.43	1,828,532	9,887	44,531

NO = number, ha = hectare

Source : Annual Report, Natural Disaster Management Division, Ministry of Agriculture, Govt. of India.

The eastern coastal states of West Bengal, Orissa, Andhra Pradesh and Tamil Nadu are affected by the cyclones originating in the Bay of Bengal during different seasons of the year. The period from January to March is a lean period from the standpoint of origin and movement of cyclones because cyclogenesis in the Bay of Bengal during this period is a rare phenomenon. A few isolated cyclones originate in the southern Bay of Bengal and affect Tamil Nadu coast. The coasts of Andhra Pradesh, Orissa and West Bengal are very often affected in May by the cyclones which originate in the southern and central Bay of Bengal and move in north-west, north and north-east direction. The period of June to September is a breeding period as most of the cyclones originate during this period in the central and northern Bay of Bengal and move west-north westwards and affect the coastal districts of Andhra Pradesh, Orissa and West Bengal. The cyclones during post-monsoon period (October-December) originate in the central and southern Bay of Bengal, move west and north-westward and mostly affect the coastal districts of Tamil Nadu and Andhra Pradesh. The 1737 cyclone of West Bengal, November 1977 and May 1990 cyclones of Andhra coast and October 1999 cyclone of Orissa coast have been the most disastrous cyclones in the history of cyclones affecting eastern coasts of India (table 26.2)

The origin and development of cyclones in the Arabian Sea during the period from January to March is of rare occurrence. Generally, they develop during the months of May, October, November and December in particular and during south-west monsoon period in general. They mostly affect the coasts of Maharashtra and Gujarat. The cyclone of June 9, 1998 was the most disastrous storm which adversely affected Gujarat. The details of cyclones of India and Bangladesh and case histories of a few disastrous cyclones have already been given in the 19th chapter of this book.

Tidal Surge-prone Areas

The tidal surge or **storm surge** refers to unusual rise in sea level caused by very low atmospheric pressure system and the stress of strong gusty wind associated with tropical cyclones on the sea surface. Tidal or storm surges, when coincide

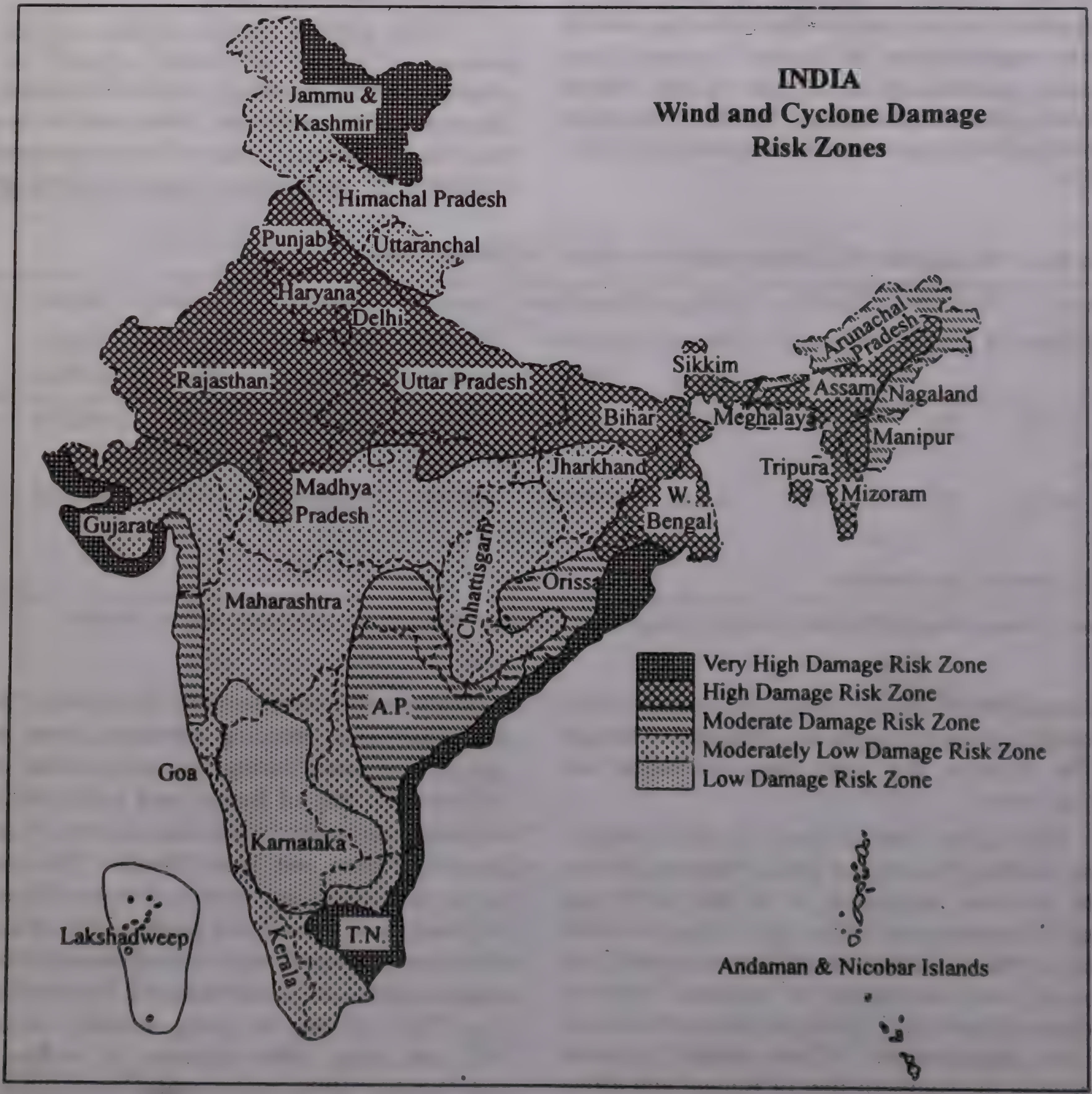

INDIA
Wind and Cyclone Damage
Risk Zones
Jammu &
Kashmir
Himachal Pradesh
Punjab
Uttaranchal
Haryana
Delhi
Rajasthan
Uttar Pradesh
Bihar
Sikkim
Arunachal
Pradesh
Assam
Nagaland
Meghalaya
Manipur
Tripura
Mizoram
Jharkhand
W.
Bengal
Madhya
Pradesh
Gujarat
Maharashtra
Chhattisgarh
Oriss
A.P.
Goa
Karnataka
Lakshadweep
Kerala
T.N.
Andaman & Nicobar Islands
Very High Damage Risk Zone
High Damage Risk Zone
Moderate Damage Risk Zone
Moderately Low Damage Risk Zone
Low Damage Risk Zone

Fig. 26.3 : Wind and cyclone damage risk zones of India. Source : UNDP Website.

with high tide, are further intensified and after intruding into the coastal lands cause widespread inundation of coastal areas and inflict great damage to human lives and property. It may be mentioned that there are no clearly demarcated areas which are frequently affected by storm surges because these are always associated with very strong cyclonic storms whose tracks are always changing. This is the reason that there is no uniform pattern of storm surge-vulnerable (prone) areas. Inspite of this, the eastern coasts are more vulnerable to storm surges than the western coasts. Indian Meteorological Department (IMD) has identified the following storm surge-prone (vulnerable) areas :

(A) **Along the east coasts**

(1) Coasts of north Orissa, and West Bengal
(2) Coasts of Andhra Pradesh between Ongole and Machilipatnam
(3) Coasts of Tamil Nadu south of Nagapattinam

(B) **Along the west coasts**

(1) coasts of Maharashtra north of Harnai
(2) south Gujarat coast
(3) costs around Gulf of Bombay
(4) coasts around Gulf of Kutch

Flood-Prone Areas

Flood hazards and disasters in India are associated with the following 3 types of floods :

- river floods caused by heavy rainfall in the catchment areas,
- storm surge floods caused by inundation of coastal areas due to high storm (tidal) surges caused by strong cyclones, and
- artificial floods or anthropogenic floods caused by natural factors such as heavy rainfall plus human activities such as construction of dams across the rivers and reservoirs behind the dams, and their mismanagement.

Most of the alluvial rivers of the country, namely the Ganga, the Yamuna, the Ram Ganga, the Gomti, the Gandak, the Kosi etc. are characterized by frequent floods almost every year. Thus the plains and riverine zones in Uttar Pradesh, Bihar and West Bengal are most vulnerable to severe floods. The flood plains of the Brahmaputra in Assam are chronic flood-prone areas. Besides, many parts of Haryana and Punjab are also flooded (fig. 26.4) in the event of heavy rains for longer duration.

The delta regions of the Mahanadi and the Brahmini in Orissa, the Godavari and the Krishna in Andhra Pradesh, and the Cauvery in Tamil Nadu are also very vulnerable to recurrent floods. Though the lower reaches of the Tapi, the Narmada and the Sabarmati are flood-prone areas but these are not affected by frequent floods. It may be mentioned that these are dammed rivers i.e. a series of dams and reservoirs have been constructed on these rivers. In the event of long duration heavy rainfall the reservoirs are filled to capacity very soon and hence huge volume of water is released from these dams which accentuate the volume of water in already swollen rivers and ultimatelly devastating floods are caused. Such situation developed in Gujarat and western Madhya Pradesh in the month of August, 2006 when the catchment areas of the Tapi, the Narmada, the Mahi, and the Sabarmati received heavy rainfall and there was sudden release of huge volume of water from Ukai and Girma dams (Tapi basin), Kadma and Panam reservoirs and Mahi Barrage (Mahi basin), Tawa dam, Sardar Sarovar Project areas (Narmada basin), Dharohi dam (Sabarmati basin) etc. All these contributed to unprecedented floods in Gujarat. The cities of Surat and Baroda reeled under flood water for several days due to mismanagement of dams. Similar situation was created in the month of August, 2006 in Karnataka and Andhra Pradesh due to sudden release of huge volume of water from the dams in the Godavari and the Krishna basins, such floods are called man-induced or anthropogenic floods.

Himanshu Thakkar of South Asia Network on Dams, Rivers and People, commented on these floods of 2006 as follows :

> "The big dams that were expected to regulate water flows were actually responsible for the floods in these states that also happen to have largest number of big reservoirs.........the natoin has paid huge costs in creating these reservoir capacities, and negligence in the dam operations is leading to disastrous consequences which are entirely avoidable."

(The Hindu, Aug. 18, 2006)

Table 26.3 : Annual damage due to heavy rains, landslides and floods

Year	Districts affected (NO.)	Villages affected (NO.)	Pop. affected (lakh)	Crop Area affected (lakh ha)	Houses damaged (NO.)	Cattle loss	EVLH (Rs. crores)	Human life loss (NO.)	EVLPP (Rs. crores)
1999	202	33,158	328.12	8.45	894,823	3,861	0.72	12,375	—
2000	200	29,964	416.24	34.79	2,736.365	102,121	631.25	3,048	389.72
2001	122	32,363	210.71	18.72	346,878	21,269	195.57	834	676.05

NO. = number, ha = hectare, EVLH = estimated value of loss to houses, EVLPP = estimated value of loss of public property.
Source : Annual Report, Natural Disaster Management Division, Ministry of Agriculture, Govt. of India.

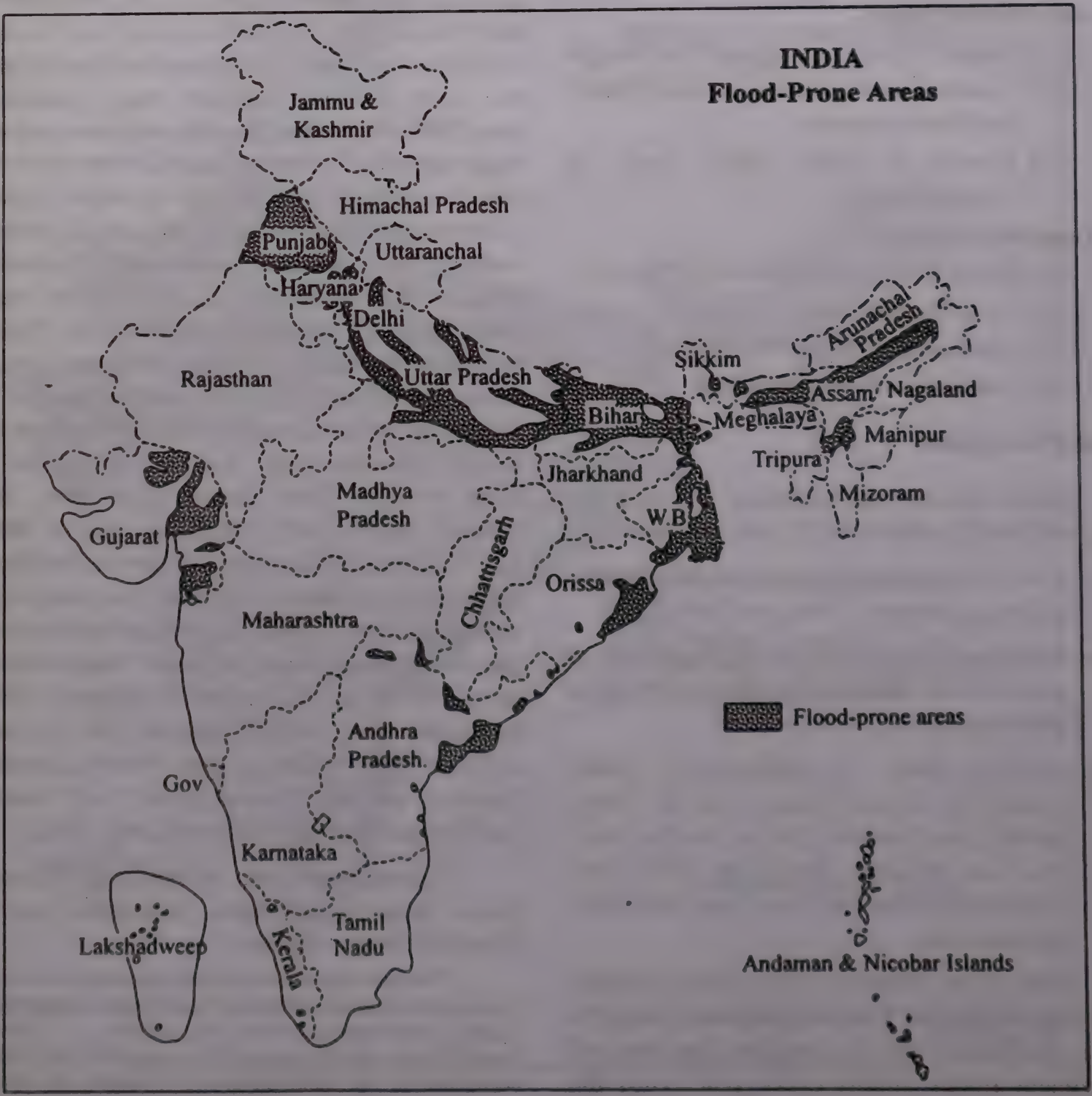

INDIA
Flood-Prone Areas
Jammu & Kashmir
Himachal Pradesh
Punjab
Uttaranchal
Haryana
Delhi
Rajasthan
Uttar Pradesh
Sikkim
Arunachal Pradesh
Assam
Nagaland
Bihar
Meghalaya
Manipur
Tripura
Mizoram
Jharkhand
W.B
Gujarat
Madhya Pradesh
Chhattisgarh
Orissa
Maharashtra
Andhra Pradesh.
Gov
Karnataka
Tamil Nadu
Kerala
Lakshadweep
Andaman & Nicobar Islands
▨ Flood-prone areas

Fig. 26.4 : Flood-prone areas of India. Source : UNDP Website.

Floods in India have been discussed in detail in the 19th chapter of this book. The country suffers heavy loss of men and material each year due to flood hazards (table 26.3).

Drought-Prone Areas

Since monsoon climate and associated rainfall is very much deceptive, irregular, and hence nearly major parts of India are affected by droughts and floods in one way or the other. For example, Rajasthan is a chronic drought-prone area but heavy rainfall during the first two weeks of July 1990, and in August 2006 caused severe floods in many parts of Rajasthan. Chronic drought-prone areas of the country include 67 districts where drought affects 25 percent of the total cropland and 12 percent people. The worst affected drought-prone zone includes the parts of the states of Rajasthan, Gujarat, Haryana, Maharashtra, Karnataka, Andhra Pradesh and southern Uttar Pradesh. Severe drought-prone areas are divided into the following 3 zones :

Zone 1

Desert and semi-arid regions spread over an area of about 600,000 km^2 and form a rectangular tract which stretches from Ahmedabad to Kanpur (to form eastern and southeastern border), from Kanpur to Julhundur (to form north-eastern and northern boundary) and form Jullundhar to Rann of Kutch along the western international border. The region is characterized by low rainfall ranging between 350 mm and 750 mm per annum but the extreme western desert areas receive even less than 350 mm annual rainfall. This zone includes whole of Rajasthan and Gujarat, western and south-western parts of Punjab, most of Haryana, south-western part of Uttar Pradesh and narrow strip along the western and north-western border of Madhya Pradesh. There is little impact of droughts in Punjab and Haryuana because sufficient irrigational facilities are available but the areas having no irrigational facilities are the worst drought-affected and famine areas of the country.

Zone 2

The second chronic drought-prone zone forms a rectangular tract which spreads over the rain shadow areas of the Western Ghats. In fact, this zone is situated to the east of the Western Ghats and extends in a width of 300 km. It includes south-western Andhra Pradesh, eastern Karnataka (east of Western Ghats) and south-western Maharasthra (east of Western Ghats). This region covers 370,000 km^2 of area and is characterized by highly erratic mean annual rainfall of less than 750 mm.

Table 26.4 : Losses due to drought damage in India

Year	Districts affected (No)	Villages affected (No)	Population affected (Lakh)	Damage to crop areas (Lakh ha)	EVDC (Rs. crores)	Cattle pop. affected (Lakh)
1999	125	—	369.88	134.22	6.44	345.60
2000	110	54,853	378.14	367.00	371.87	541.67
2001	103	22,255	86.19	67.44	NA	34.28

No. = number, ha = hectare, EVDC = estimated value of loss of damaged crops, pop.= population.

Source : Annual Reports, Natural Disaster Management Division, Ministry of Agriculture, Govt. of India.

Zone 3

Besides the aforesaid two broad zones of severe droughts, there are some scattered pockets of droughts in the country such as Tirunelveli district located to the south of Vagai river, Coimbatore area, Palamau area of Jharkhand, Purulia district of West Bengal, Kalahandi region of Orissa etc. The scattered pockets of drought-prone areas cover about 100,000 km^2 of area.

The Ministry of Agriculture has identified drought affected areas in the country on the basis of rainfall distribution, frequency of occurrence of drought and percentage of irrigation. On the other hand, the Irrigation Commission has demarcated drought-prone areas on the basis of rainfall and irrigation in the region concerned. Thus according to the Irrigation Commission those areas are drought affected areas which have less than 1000 mm of mean annual rainfall, 20 per cent or more of the years do not receive even 75 per cent of this annual amount of rainfall and where irrigated areas are less than 20 per cent of the cropped areas.

Landslide-Prone Areas

Landslides are mainly associated with hillslopes and thus there are two major areas which are vulnerable to landslides as follows :

- ➤ Himalayan region, and
- ➤ Western Ghats region

The most vulnerable areas to landslides in the Himalayan region are in the states of Jammu and Kashmir, Himachal Pradesh, Uttarakhand, Sikkim, West Bengal, and Assam. The Garhwal and Kumaun Himalayas in Uttarakhand and Darzeeling Himalaya in West Bengal are most vulnerable to recurrent landslides because of construction of numerous roads along the spurs of hillslopes in order to connect places of religious faith and tourist destinations. Besides, large-scale deforestation has also been responsible for frequent landslides in the Himalayan regions of India, and Western Ghats region.

Tsunami-Prone Areas

Since tsunamis are sea phenomena (waves) as these are caused by undersea earthquakes exceeding 7.0 magnitude on Richter scale, and hence immediate lowland coastal areas and shallow seas are most vulnerable to tsunamis. Before the incidence of December 26, 2004 tsunami tragedy, Indian coasts were considered free from this disaster. The occurrence of Sumatra tsunami on December 26, 2004 has shattered this myth. Since the subduction zone along the convergence zone of Indian and Burmese plates is very active, there is every likelihood for the occurrence of undersea seismic events and resultant tsunami waves. Thus, the eastern coasts are most vulnerable to tsunami waves, whenever these are generated. The seismic events along Gujarat coasts and adjoining coastal areas of Pakistan may generate powerful tsunami waves which may affect the western coast of India.

26.2 : INSTITUTIONAL ORGANIZATION AND POLICY FRAMEWORK OF DISASTER MANAGEMENT

Basically, the responsibility for disaster reduction and management rests with the concerned state governments (where a particular disaster strikes) and the central government's responsibility lies in two aspects i.e. (1) to provide financial and logistic support to the disaster-affected state/states, and (2) to coordinate various aspects of disaster management at ministerial, organizational, state governments, and departmental levels.

There has been major paradigm shift in disaster management in India after the killer tsunami waves caused devastation on the eastern coasts of Tamil Nadu and Andhra Pradesh, western coasts of Kerala, and Andman and Nicobar Islands on December 26, 2004. Previously, the institutional organization and policy framework of disaster management was oriented towards post-disaster management i.e. more attention was paid towards the execution of rescue operation, relief work, rehabilitation, and recovery aspects but the new framework pays more attention on pre-disaster aspects of disaster management i.e. (1) preparedness, prediction and warning, (2) disaster mitigation, and (3) disaster prevention. It is, thus, imperative to discuss both scenarios of disaster management : (1) existing scenario, and (2) planned scenario.

(1) Existing Scenario

In fact, before the enactment of National Disaster Management Authority in 2005, there was no permanent establishment for disaster management, rather there was adhoc arrangement for rescue operation, relief work, rehabilitation and reconstruction whenever a disaster occurred. The following are the institutional mechanisms for disaster management :

(1) Cabinet Commttee on Natural Calamities (CCNC)

(2) National Crisis Management Committee (NCMC)

(3) Crisis Management Group (CMG)

The central government is the appex body of disaster management as it provides financial and logistic assistance to the concerned states and Union territories where a major disaster occurs, coordinates the works undertaken by different ministries, departments, organizations including NGOs and plays a supervisory role. The pre-existing Cabinet Committee on Drought Management (CCDM) has been reconstituted as Cabinet Committee on Natural Calamities (CCNC) which is headed by the Prime Minister. Previously, the scope of CCNC was limited to post-disaster measures (rescue, relief work, reconstruction, rehabilitation etc.) but now its scope has been extended to include pre-disaster measures, such as disaster preparedness, disaster mitigation and disaster prevention.

There is a High Level Committee of Ministers (HLCM) headed by the minister of agriculture. This committee deals with the financial support to be given to the concerned state governments. There is also a National Calamity Contingency Fund (NCCF) under HLCM.

The Cabinet Committee on Security (CCS) looks after the nuclear, biological and chemical disasters and emergencies.

The National Crisis Management Committee (NCMC) consisting of secretaries of various ministries, departments and organizations as its members is headed by the cabinet secretary. The NCMC issues directions and instructions to the Crisis Management Group (CMG) as and when required in connection with the management of disasters. The Central Relief Commissioner in the Ministry of Home Affairs becomes the chairman of CMG, which consists of senior officers from various ministries. The members of CMG are called 'nodal officers'. The main functions of CMG are to review the plans and projects framed by various ministries in relation to disaster management, to coordinate different activities (related to disaster management) undertaken by various central ministries and state governments, and to obtain information related to steps taken for disaster management from the nodal officers.

(2) Present Scenario

The Disaster Management Bill was passed by the Parliament in 2005 so as to constitute National Disaster Management Authority (NDMA) and State Disaster Management Authority (SDMA) and various committees, funds, and forces. The following are the institutional and organizational structures under Disaster Management Act :

- National Disaster Management Authority (NDMA) under the chairmanship of Prime Minister.
- State Disaster Management Authority (SDMA) headed by the chief minister of the concerned state.
- District Disaster Management Authority (DDMA) under the chairmanship of district magistrate/collector of the district.
- National Disaster Response Force (NDRF).
- Natinoal Institute of Disaster Management (NIDM).
- National Fund for Disaster Response (NFDR).
- National Fund for Disaster Mitigation (NFDM).

It may be mentioned that the Disaster Management Act has now institutionalized disaster management and coordination of pre and post-disaster management measures of disaster preparedness, disaster mitigation, disaster prevention, rescue operation, relief work, rehabilitation, reconstruction and recovery at the national, state and district levels (and also at Block and Taluka level). The total number of membership of NDMA cannot exceed 10 members.

National Policy on Disaster Management

The following are the salient features of National Policy on Disaster Management as released by the Ministry of Home Affairs (Govt. of India (A Status Report on Disaster Management in India, August, 2004) :

It may be mentined that the following features of National Policy on Disaster Management as released by the Ministry of Home Affairs were drafted for the Disaster Management Bill, 2005 :

- Adoption of a holistic and pro-active approach towards prevention, mitigation and preparedness.
- Incorporation of mitigation measures in the on-going schemes/programmes.
- Each Ministry/ Department of the Central/ State Government will set apart an appropriate quantum of funds under the Plan for

specific schemes/projects addressing vulnerability reduction and preparedness.

- Where there is a shelf of projects, projects addressing mitigation will be given priority.
- Each project in a hazard-prone area to have mitigation as an essential term of reference and to include a statement indicating as to how the project addresses vulnerability reduction.
- Community involvement and awareness generation, particularly that of the vulnerable segments of population and women has been emphasized as necessary for sustainable disaster risk reduction. This is a critical component of the policy since communities are the first responders to disasters and therefore, unless they are empowered and made capable of managing disasters, any amount of central support cannot lead to optimal results.
- Interaction with the corporate sector, non-governmental organizations and the media in the national efforts for disaster prevention/vulnerability reduction.
- Building up institutional structures/appropriate chain of command and imparting appropriate training to disaster managers at various levels to ensure coordinated and quick response and development of inter-State arrangements for sharing of resources during emergencies.
- Inculcating a culture of planning and preparedness at all levels for capacity building measures.
- Formulation of Standard Operating Procedures (SOPs) and disaster management plans at state and district levels as well as by relevant central government departments.
- Compliance with construction designs laid down in relevant Indian Standards.
- Evaluation and, where necessary, retrofitting of lifeline buildings in seismic zones III, IV & V-hospitals, railway stations, airports/airport control towers, fire station buildings, communication network, major administrative buildings.
- Conversion of relief codes into disaster management codes for institutionalizing the planning processes.
- Promotion of international cooperation in the area of disaster response, preparedness and mitigation in tune with national strategic goals and objectives.

Reproduced from Disaster Management in India-A Status Report, Govt., of India, Ministry of Home Affairs.

Responsibilities of NDMA

The following will be the responsibilities of the National Disaster Management Authority :

- Providing necessary support and assistance to State Governments by way of resource data, macro-management of emergency response, specialized emergency response teams, sharing of disaster related data base etc.
- Coordinating/mandating Government's policies for disaster reduction/mitigation.
- Ensuring adequate preparedness at all levels in order to meet disasters.
- Coordinating response to a disaster when it strikes.
- Assisting the State Governments in coordination of post-disaster relief.
- Coordinating resources of all Central Government Departments/agencies involved.
- Monitor and introduce a culture of building requisite features of disaster mitigation in all development plans and programmes.
- Any other items of work may be entrusted to it by the Government.

Source : National Disaster Management Division, Ministry of Home Affair, Govt. of India.

The National Disaster Management Act, 2005 has also enabled the State Governments to enact State Disaster Management Acts (SDMA). The state governments are also desired to convert the existing relief codes into Disaster Management Codes.

26.3 : DISASTER MANAGEMENT STRATEGIES

As stated earlier, after December, 26, tsunami tragedy there has been major shift in the disaster management strategies in India. Previously, more attention was paid towards post-disaster stage of disaster management which included rescue operation, relief work, rehabilitation, reconstruction and recovery processes but now disaster preparedness, disaster mitigation and disaster prevention, have more focussed attention. In fact, mitigation and prevention of disasters have been now taken as essential components of development strategies of the Govt. of India. Thus, the disaster management in India includes the following strategies :

1. Pre-disaster stage

- ➤ disaster preparedness
- ➤ disaster mitigation
- ➤ disaster prevention

2. Post-disaster stage

- ➤ rescue operation
- ➤ relief work
- ➤ rehabilitation
- ➤ reconstruction and recovery

The principles and steps of aforesaid strategies of disaster management have been discussed at length in the 17th chapter of this book, and hence these are not elaborated here, but the pre-disaster strategies being pursued in the cases of individual disasters in India are being discussed below :

1. Earthquake Risk Mitigation

It may be mentioned that here the term 'mitigation' is used in wider sense so as to also include disaster preparedness and disaster prevention in its ambit. It is also important to note that it is not the earthquake that kills people, rather it is the buildings that kill people, and hence main focus of earthquake risk mitigation is towards building construction standards as per Bureau of Indian Standard (BIS) codes. Most of the existing buildings in the earthquake-risk zones are non-engineered construction. The earthquake-prone areas have been divided into 5 earthquake risk zones (already discussed in this chapter) and a comprehensive earthquake risk zones map has been prepared (fig. 26.2) for mitigation purpose. The government of India has taken the following measures for earthquake risk mitigation.

(1) Constitution of National Core Group (NCG) : The government has constituted a National core Group for the mitigation of earthquake risks. This core group consists of persons having expertise in earthquake engineering, and administrators at various levels. The NCG has been assigned the following responsibilities for the prevention and mitigation of earthquake risks and damages :

- ➤ to prepare strategies and action plans to reduce the adverse impacts of seismic events.
- ➤ to issue necessary advices and appropriate guidelines to state governments related to different aspects of earthquake risk mitigation.
- ➤ to develop appropriate building plans and designs for earthquake-resistant construction and to issue construction manuals in the form of booklets, magazines, pamphlates etc.
- ➤ to develop such systems which may enable the states of earthquake-vulnerable areas to adopt BIS codes in their building byelaws.
- ➤ to evolve suitable systems to test the knowledge of architects and engineers and to enable them to learn BIS codes and updated byelaws.
- ➤ to evolve mechanism for proper training of engineers of municipal corporations of earthquake-vulnerable cities.
- ➤ to arrange training for professional engineers and architects of private sectors so as to enable them to learn BIS codes and updated byelaws.
- ➤ to evolve suitable systems to test the knowledge of architects and engineers and to issue them certificates to this effect.
- ➤ to evolve system for the training of masons for acquainting them with the use of appropriate building designs and materials.

(2) Review of building byelaws and their adoption : As stated earlier that it is the buildings that kill people as the structural failure causes mass collapse of buildings killing hundreds to thousands of people. Thus, structural mitigation is very important aspect of earthquake-risk mitigation programmes. The state governments are desired to review their existing building bye-laws and wherever and whenever necessary they should amend them so as to protect the buildings from structural failure (collapse) when an earthquake disaster occurs. If needed, appropriate amendments in the existing Town and Country Planning Acts, Land Use Zoning Regulations, Development Control Regulations and Building Byelaws would be made as and when advised by the NCG for earthquake risk mitigation so that updated BIS codes may be adopted by the state governments and local bodies. The Model Building Byelaws (MBB) ensure technical implementation of safety aspects of buildings.

(3) **An Appex Committee** has been constituted to review and update Bureau of Indian Standards (BIS) Codes which are appropriate for multi-hazard resistant design and construction. The committee comprises representatives from the Ministries of Consumer Affairs, Home Affairs and BIS.

(4) Constitution of Hazards Safety Cells (HSC) : Provisions have been made to establish HSC in different states. The chief engineer of the State PWD becomes the chairman of the cell. The prime responsibility of the HSC is to develop systems and mechanisms for the implementation of building codes in the construction of government buildings to ensure safety of buildings from different hazards. Besides, the HSC would also be responsible for the review of designs of all government buildings, for acting as an advisory cell to the state government in relation to safety of all government buildings.

Besides the aforesaid major earthquake disaster mitigation measures, the following are other important measures in this regard :

- National programme for capacity building of engineers and architects in earthquake risk mitigation.
- Training programmes of rural masons so that they may be trained in multi-hazard resistant construction of buildings. Such training programmes are run in collaboration with Housing and Urban Development Corporation (HUDCO).
- Inclusion of earthquake engineering in the undergraduate engineering and architecture curricula in consultation with all India Council of Technical Education (AICTE) and Council of Architecture (COA).
- Retrofitting of all existing lifeline buildings such as hospitals, schools and colleges, government offices, cinema halls, multistoried apartments and malls.
- Provision for national earthquake risk mitigation project with the consultation of Planning Commission for detailed evaluation and retrofitting of lifeline buildings in the multi-hazard zones, such as government administrative buildings, buildings of railways, airways (air ports), telecommunications buildings, bus stations etc. in earthquake risk zones IV and V.
- Implementation of 'accelerated urban earthquake vulnerability reduction programme' in 38 cities in seismic zones III, IV and V with a population of 500,000 and above. These cities include Deharadun, Delhi, Srinagar, Jammu, Amritsar, Jalundhar, Jamnagar, Ahmedabad, Rojkot, Bhavnagar, Surat, Mumbai, Bhiwandi, Nasik, Agra, Varanasi, Lucknow, Bareily, Meerut Kanpur, Patna, Asansol, Kolkata, Guwahati, Cuttack, Dhanbad, Bhubanehwar, Jabalpur, Indore, Vadodara, Pune, Vijayawada, Mangalore, Kochi, Kozhikod, Coimbatore, Trivandrum, and Chennai.
- Financial assistance is provided from National Calamity Contingency Fund (NCCF) and Calamity Relief Fund (CRF).

2. Cyclone Disaster Management

The pre-disaster stage of the management of cyclone disaster in India includes strategies for preparedness and mitigation programmes. The cyclone prediction and forewarning are very important aspects of cyclone disaster management programmes.

The Indian Meteorological Department (IMD) with its headquarters at Delhi handles and coordinates all aspects of cyclone forecasting and cyclone warning and thus the IMD has well developed **'cyclone warning system'** and **'cyclone warning dissemination system'** which include the following steps :

- Tracking of cyclones through cyclone surveillance radars located at Kolkata, Paradeep, Visakhapatnam, Machilipatnam, Chennai and Karaikal on the east coast and at Cochin, Goa, Mumbai, and Bhuj on the west coast.
- Satellite images receiving equipments have been installed at Delhi, Mumbai, Pune, Chennai, Visakhapatnam, Kolkata, Chennai, Mumbai, and Guwahati.
- The satellite pictures and information so received are collected at Meteorological Data Utilization Center (MDUC) at New Delhi and are further disseminated to all other forecasting offices through Radio Facsimile.
- Area Cyclone Warning Centres (ACWCs) have been located at Kolkata, Chennai and Mumbai.
- Cyclone Warning Centers (CWC) have been established at Bhubaneshwar, Visakhapatnam and Ahmedabad.
- The forecasting of cyclones originating in the Bay of Bengal is handled by the ACWC at Kolkata, and Chennai, and CWC at Bhubaneshwar and Visakhapatnam, while the ACWC at Chennai and Mumbai and CWC at Ahmedabad are responsible for the forecasting of cyclones of the Arabian Sea. The National Forecast Center at Pune coordinates the forecasting programmes of cyclones of both the Bay of Bengal and the Arabian Sea.
- Computarised Operational Advisory Forecasts (COAF) of the movement of cyclones originating in the Bay of Bengal and the Arabian Sea are issued by the Numerical Weather Prediction (NWP) Division of the IMD, located at New Delhi.
- There are two stages of issuing of warnings of cyclones as follows :
  (1) First stage of **Cyclone Alert** : warning of the movement of cyclones is issued 48 hours in advance of the expected arrival of cyclones and associated bad weather conditions in the coastal areas.
  (2) Second stage of **Cyclone Warning** : cyclone warning is issued 24 hours in advance of the expected attack of the storms at particular location (s) of coastal area.
- Cyclone warnings and messages are issued to the chief secretaries, relief commissioners and district magistrates/collectors of concerned states. The offices of these authorities transmit cyclone warnings and messages through electronic and print media to general public.
- Storm surges information/advisories are issued to the ACWC and CWC by the Northern Hemispheric Analysis Center (NHAC) at New Delhi.

A National Core Group on Cyclone Mitigation (NCGCM) has been constituted for cyclone monitoring and mitigation. This group comprises the experts from IMD, National Center for Medium Range Weather Forecasting, Central Water Commission, National Remote Sensing Agency etc. Besides, a National Cyclone Mitigation Project (NCMP) has been prepared with the following objectives :

- construction of cyclone shelters,
- coastal belt plantation in storm surge-prone areas,
- strengthening of cyclone warning system, training and education etc.

3. Landslide Disaster Mitigation

The pre-landslides hazard management includes the strategies of preparedness, mitigation and prevention. There are two major institutional measures for landslide hazards mitigation as follows :

(1) **Nodal Agency** : The Geological Survey of India (GSI) has been designated nodal agency by the Govt. of India with the following responsibilities :

- to undertake and coordinate geological studies in the landslide-prone areas.

- to demarcate landslide zonation and to prepare landslide risk zones maps.
- to monitor the occurrences of landslides and avalanches.
- to find out factors and causes of the occurrences of landslides and suggest precautionary and preventive measures of occurrences of landslides of different types.

(2) **National Core Group :** A National Core Group for landslide mitigation has been constituted under the chairmanship of the Secretary, Border Management. This core group consists of the Secretary, Department of Science and Technology, Govt. of India, Secretary, Road Transport and Highways, and the heads of GSI and National Remote Sensing Agency (NRSA) with the following objectives :

- to prepare strategies and plans of actions for mitigating the impacts of landslides.
- to advise and guide the State Governments relating to various aspects of landslide reduction and mitigation.
- to monitor the activities related to landslide mitigation.
- to evolve early landslide warning systems.
- to evolve protocols for landslide risk reduction.

4. Tsunami Disaster Management

All aspects of tsunami management i.e. pre and post-tsunami management in India have been discussed in much detail in the 18th chapter of this book. These aspects are not discussed here in order to avoid repetetion but the summary is presented here.

Pre-tsunami disaster management includes preparedness, mitigation and prevention programmes as follows :

- Identification and mapping of the areas of tsunamigenic undersea earthquakes.
- Demarcation of coastal regulation zone (CRZ) and to mkae it free from human settlements and dense structures except a few important installations such as military bases.
- Protection and conservation of natural lines of protection from tsunami waves such as coastal dunes, beaches, mangroves, corals etc.
- Installation of tsunami meters, tracking of undersea earthquakes and resultant tsunami waves.
- Provisions for early tsunami warning system (TWS) and preparedness for timely evacuation of people living in danger coasal zone to safer places.

Post-tsunami disaster mangement includes the following measures :

- Rescue and evacuation of stranded alive people,
- Immediate relief work,
- Reconstruction and recovery, and
- Rehabilitation.

The government has initiated the steps for the installation of Indian Ocean Tsunami Warning System and Mitigation (IOTWS) in association with Australia, Indonesia, Iran, Malaysia, Pakistan and Thailand. Under IOTWS US-made DART (Deep Ocean Assessment and Reporting of Tsunami) would be installed. India is planning to create Tsunami and Storm Surge Warning Systems (TSSWS) at an estimated cost of Rs. 125 crores which would be operational by 2007. This system requires placing of 20-25 automated sea level gauges along the east and west coasts. Besides, 10-12 DART type deep sea pressure sensors and sea level buoys would be deployed to track tsunami and storm/tidal surge waves on east and west coasts.

5. Flood and Drought Disaster Management

Different aspects of flood and drought management in India have been discussed in the 19th chapter of this book and hence these are not reproduced here in order to avoid repetetion.

26.4 : ENVIRONMENTAL LAWS

The laws regarding environmental protection in India include acts, rules and notifications. All aspects of environmental laws in India are now included under the Environmental Protection Act (EPA) which was enacted in 1986 after the Bhopal Gas Tragedy. The EPA is considered an **'umbrella legislation'** because it not only covers all the pre-existing and new laws but it also filled many gaps and removed lacunae in the existing environmental laws. Three major policies are the basic structure for environmental protection as follows :

- The National Forest Policy, 1988,
- Policy statement for abatement of pollution, 1992, and
- National conservation strategy and policy statement on environment and development, 1992.

It may be mentioned that there is constitutional provision for the protection of environment wherein the responsibility of the State towards environmental protection has been clearly laid down as follows :

> *'The State shall endeavour to protect and improve the environment and to safeguard the forests and wildlife of the country.'*

Similarly, the responsibility and duty of the citizens of India have also been laid down in the constitution as given below :

> *'It shall be the duty of every citizen of India to protect and improve the natural environment including forests, lakes, rivers and wildlife and to have compassion for living creatures.'*

The state governments have also been held responsible for the protection of environment and wildlife under 42nd amendment of the Constitution of India. The Article 48-A, under Directive Principles of State Policy, has made it the responsibility and duty of the state government to 'protect and improve the environment, and to safeguard the forests and wildlife of the country', while Article 51-A (g), under Fundamental Duties, has made it the fundamental duty of every citizen of India to 'protect and improve the natural environment including forests, lakes, rivers, and wilfelife and to have compassion for living creatures.'

The Seventh Schedule of the Constitution of India includes the following subjects which are related to environment :

Union List-I

Entries

52- Industries
53- Regulation and development of oil fields and mineral oil resources.
54- Regulation of mines and mineral development.
56- Regulation and development of Inter-State rivers and river valleys.
57- Fishing and fisheries beyond territorial waters.

State List-II

Entries

6- Public health and sanitation
14- Agriculture, protection against pest and prevention of plant diseases.
18- Land, consolidation etc.
21- Fisheries
23- Regulation of mines and mineral development subject to the provision of Lsit I
24- Industries subject to the provision of List I

Common/Current List

Entries

17 A- Forests
17 B- Protection of wild animals and birds
20- Economic and social planning
20 A- Population control and family planning

ENVIRONMENTAL PROTECTION ACT (EPA), 1986

Definitions under Section 2 of EPA

(a) **'Environment'** includes water, air and land and the interrelationships which exist among and between water, air and land, and human beings, other living creatures, plants, micro-organisms and property.

(b) **'Environmental Pollutant'** means any solid, liquid or gaseous substance present in such concentration as may be, or tend to be, injurious to environment.'

(c) **'Environmental Pollution'** means the presence in the environment of any environmental pollutant.

(d) **'Hazardous Substance'** means any substance or preparation which, by reason of its chemical or physical-chemical properties or handling, is liable to cause harm to human beings, other living creatures, plants, micro-organisms, property or the environment.

General Powers of Central Govt. Under EPA, 1986

(1) Co-ordination of actions by the State Govt. officers and other authorities,

(2) Planning and execution of a nation-wide programme for prevention, control and abatement of environmental pollution,

(3) Laying down standards for the quality of environment in its various aspects,

(4) Laying down standards for emission or discharge of environmental pollutants from various sources whatsoever,

(5) Restriction of areas in which any industries, operations or processes or class of industries, shall not be carried out subject to certain safeguards,

(6) Laying down procedures and safeguards for the prevention of accidents which may cause environmental pollution and remedial measures for such accidents,

(7) Laying down procedures and safeguards for the handling of hazardous substances,

(8) Examination of such manufacturing processes, materials and substances as are likely to cause environmental pollution,

(9) Carrying out and sponsoring investigation and research relating to problems of environmental pollution,

(10) Inspection of any premises, equipment, machinery, manufacturing or other processes, materials or substances and giving, by order, of such directions to such authorities, officers or persons as it may consider necessary to take steps for the prevention, control and abatement of environmental pollution,

(11) Extablishment or recognition of environmental laboratories and institutes to carry out the functions entrusted to such environmental laboratories and industries under this Act,

(12) Collection and dissemination of information in respect of matters relating to environmental pollution,

(13) Preparation of manuals, codes or guides relating to the prevention, control and abatement of environmental pollution, and

(14) Such other matters as the Central Government deems necessary or expedient for the purpose of securing the effective implementation of the provisions of the Act (EPA, 1986).

General Environmental Laws

1986 : The Environment Protection Act (EPA, 1986) as elaborated above.

1986 : The Environment (Protection) Rules, 1986, lay down procedures for setting standards of emission of discharge of environmental pollutants.

1989 : The Hazardous waste (Management) Rules, 1989, are meant to control the generation, collection, treatment, import, storage and handling of hazardous waste.

1989 : The Manufacture, Storage and Import of Hazardous Chemicals Rules, 1989, relate to define terms and setup an authority to inspect, once a year, the industrial activity related with hazardous chemicals and isolated storage facilities.

1989 : The Manufacture, Use, Import, Export and Storage of Hazardous Micro-organisms/Genetically Engineered Organisms or Cells Rules, 1989, to protect the environment, nature and health, in connection with the application of gene technology and micro-organisms,

1992 : The Public Liability Insurance Act and Rules Amendment, 1992, to provide for public liability insurance for the purpose of providing immediate relief to the persons affected by accident while handling any hazardous substances.

1995 : The National Environmental Tribunal Act, 1995, to award compensation for damages to persons, property, and the environment arising from any activity involving hazardous substances,

1997 : The National Appellate Authority Act, 1997, to hear appeals with respect to restrictions of areas where industries are set up or prescribed subject to certain safeguards under the EPA, 1986.

1998 : The Biomedical Waste (Management and Handling) Rules, 1998, are legally binding on the health care institutions to streamline the process of proper handling of hospital waste such as segregation, disposal, collection, and treatment.

1999 : The Environment (Siting for Industrial Projects) Rules, 1999, lay down detailed provisions related to areas to be avoided for siting of industries, precautionary measures to be taken for the selection of sites.

2000 : The Municipal Solid Waste (Management and Handling) Rules, 2000, which make every municipal authority responsible for proper collection, separation, storage, transportation, processing, treatment and disposal of solid wastes.

2000 : The Ozone Depleting Substances (Regulation and Control) Rules, 2000, for the regulation of production and consumption of ozone depleting substances (such as CFCs).

2002 : The Noise Pollution (Regulation and Control) (Amendment) Rules, 2002, to formulate terms and conditions which are necessary to reduce noise pollution, to lay down rules to permit use of loudspeakers or public address systems during night hours or during any cultural or religious festivals.

2002 : The Biological Diversity Act, 2002, to provide provisions for the conversation of biological diversity, sustainable use of its components, and fair and equitable sharing of the benefits arising out of the use of biological resources and knowledge associated with biodiversity.

WATER POLLUTION LAWS

(Central Laws)

1956 : The River Boards Act, 1956

1970 : The Merchant Shipping (Amendment) Act, 1970

1974 : The Water (Prevention and Control of Pollution) Act, 1974

1975 : The Water (Prevention and Control of Pollution) Rules, 1975

1975 : The Water (Prevention and Control of Pollution) (Procedure for Transaction of Business) Rules, 1975

1977 : The Water (Prevention and Control of Pollution) Cess Act, 1977

1978 : The Water (Prevention and Control of Pollution) Act 1974, as amended in 1978 and 1988

The Water (Prevention and Control of Pollution) Cess Rules, 1978

1991 : Notifications on Central Water Laboratory, 1988, 1991. The Water (Prevention and Control of Pollution) Cess Act, 1977, as amended in 1991

1991 : The Coastal Regulation Zone Notification, 1991

AIR POLLUTION LAWS

(Central)

The Indian Boilers Act, 1923

The Factories Act, 1948

The Industries (Development and Regulation) Act, 1951

The Mines and Minerals (Regulation and Development Act, 1947

The Air (Prevention and Control of Pollution) Act, 1981

The Air (Prevention and Control of Pollution) Rules, 1982.

The Air (Prevention and Control of Pollution) (Union Territories) Rules, 1983.

The Air (Prevention and Control of Pollution) Act, 1981, as amended in 1987

Notifications on the date from which the Act came into force, 1981, 1988

Notifications on Declaration of Air Pollution Control Areas, 1981, 1987, 1988, 1988, 1988, 1989

Notification on Emission Standards of Pollutants from Various Industries, 1986

Radiation Laws

The Atomic Energy Act, 1962

Radiation Protection Rules, 1971

Pesticides Laws

The Poison Act, 1919

The Factories Act, 1948

The Insecticides Act, 1968

Notification on Environmental Laboratories and Analysis, 1987

Others

The Indian fisheries Act, 1987

The Indian Forest Act, 1927

The Prevention of Food Adulteration Act, 1954

The Ancient Monuments and Archeological Sites and Remains Act, 1958

The Wildlife (Protection) Act, 1972

The Urban Land (Ceiling and Regulation) Act, 1976

The Forest Conservation Act, 1980

The Environment Protection Act, 1986

Notification on the Environment (Protection) Rules, 1986

Notifications of Authorised Officers/Agencies to enter the Premises for Inspection, 1987

Notifications on constitution of Appellate Authorities under the Act, 1988, 1992

Hazardous Waste (Management and Handling) Rules, 1989

Manufacture, Storage and Import of Hazardous Chemical Rules, 1989

Notification on Micro-organisms Genetically Engineered Organisms or Cells, 1989 (Notified under EPA, 1986)

Resolution on Scheme on Labelling of Environment Friendly Products (ECOMARK), 1991

Public Liability Insurance Act, 1991, as amended in 1992

Public Liability Insurance Rules, 1991

Notifications on Delegation of Powers as State Board by the Central Board to Various Union Territory Administrations 1988, 1991, 1992, 1992

Notifications on Officers/Agencies Authorised to take Samples, 1988, 1988, 1988, 1988, 1989, 1991

Notifications on Constitution of Appellate Authority, 1989

Notifications on Guidelines for Location of Industries, Mining Operations, etc. for Various Areas, 1989, 1989, 1990, 1990, 1991, 1991, 1991

Notification on Officers Authorised for taking Cognisance of Offences, 1991

Notification on Restricting Certain Activities in specified area of Aravalli Range, 1992

Environmental Impact Assessment Notification, 1994, as further amended in 1994

STATE LAWS

Water Pollution

Orissa River Pollution (Prevention) Act, 1953

Maharashtra Prevention of Water Pollution Act, 1969

Smoke Control

The Bengal Smoke Nuisance Act, 1905

The Gujarat Smoke Nuisance Act, 1963

The Bombay Smoke Nuisance Act, 1912

Pest control

The Andhra Pradesh Agricultural Pest and Disease Act, 1919

The Assam Agricultural Pests and Disease Act, 1954

The UP Agricultural Disease and Pests Act, 1954

The Mysore Destructive Insects and Pests Act, 1917

The Kerala Agricultural Pests and Disease Act, 1958

Wildlife Act, 2006

The Wildlife (Protection) Amendment Act became effective in 2006. This Act provides provision for the creation of Tiger Conservation Authority and the Tiger and Other Endangered Species Crime Control Bureau (Wildlife Control Bureau) with the following objectives and duties :

- to collate intelligence relating to wildlife crime,
- to ensure cooperation with the States through its set-up,
- to develop infrastructure,
- to develop capacity building for scientific and professional investigation into wildlife crime, and
- to assist the States in the successful prosecution of such crimes.

The offenders shall be punished with imprisonment for not less than 3 years but may extend upto 7 years, and also with fine not less than Rs. 50,000 but may extend upto Rs. 200,000.

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Publications (Books) : (1) पर्यावरण भूगोल, (2) जलवायु विज्ञान, (3) जलवायु एवं समुद्र विज्ञान, (4) भौतिक भूगोल का स्वरूप, (5) भूआकृति विज्ञान का स्वरूप, (6) जैव भूगोल, (7) समुद्र विज्ञान, (8) Geomorphology, (9) Physical Geography, (10) Environmental Geography, (11) Climatology, (12) Oceanography, (13) Biogeography, (14) Environmental Management (edited), (15) Geomorphology and Environment (1988) (edited), (16) Geomorphology and Environment (2005) (edited), (17) Geo-environmental Planning in India (research monograph), (18) Gully Erosion and Management : (research monograph) (18 books);

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